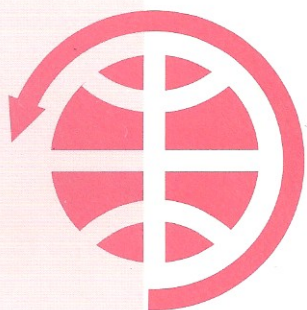




AMSAT
RADIO AMATEUR SATELLITE
CORPORATION

PROCEEDINGS OF THE
AMSAT-NA

Space Symposium and Annual Meeting

October 8-10
2010
Chicago/Elkgrove,
Illinois

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Radio Amateur Satellite Corporation



**Proceedings of the 2010
AMSAT-North America 28th
Space Symposium and
Annual Meeting
October 8, 9, 10, 2010
Chicago/Elk Grove, IL**

Radio Amateur Satellite Corporation

Celebrating 41 years of Amateur Radio in Space

850 Sligo Avenue
Suite 600
Silver Spring, MD 20910

Phone 301-589-6062

Fax 301-608-3410

<http://www.amsat.org>

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AMSAT

The Radio Amateur Satellite Corporation
850 Sligo Avenue, #600
Silver Spring, MD 20910
Phone 301-589-6062 • Fax 301-608-3410

Welcome to Chicago!

It is with great pleasure that I personally welcome you to the 2010 AMSAT-NA Annual Meeting and Space Symposium. Once again, this meeting continues a tradition started in the early 1980's to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas.

In 2009-2010 we adopted the direction set by the strategy developed by the Engineering Task Force for AMSAT's future projects in space. We have re-designed and re-developed SuitSat II into ARRISat-1 when conditions aboard the International Space Station drove RSC-Energia, NASA, and AMSAT to develop a new strategy for one of the most popular amateur space projects ever. At this year's Symposium you will see first hand this remarkable technology using the spacecraft prototype and a simulator of the student experiment. Two spacecraft have been shipped to RSC-Energia in Moscow; one is the flight unit and the second is a flight spare. Deployment from the ISS is expected in First Quarter 2011.

Due to the effort required to get ARISSat-1 ready for flight this year AMSAT's Project Fox CubeSat has made slower progress than originally planned. With the deployment of ARISSat-1 AMSAT's engineering resources will be turned loose on our next satellite.

AMSAT has strengthened ties to the educational community with the extension of the mentorship program started in the 2009-2010 academic year involving AMSAT, the IBM Watson Research Center, and SUNY-Binghamton. We are hoping to build on the work accomplished last year with their design of deployable solar panels and preliminary work on using super capacitors for power storage. AMSAT continues in negotiations to establish a presence on the University of Florida campus.

We have accomplished much this year. Forty-one years of Amateur Radio in space continues to accomplish remarkable systems. Your continued support will provide a bright future.

73,

Barry A. Baines, WD4ASW
President

AMSAT's Opportunities in Education

ARISS = Education

ARISS inspires and engages youths in science, technology, engineering, math and Amateur Radio. Here are ideas to help you get your school or youth group involved.

By Rosalie White, K1STO
US ARISS Delegate
ARISS-International Secretary-Treasurer
ARRL ARISS Program Manager

Inspire and Engage

What's the best way to tell youths about the fun and technological excitement of Amateur Radio? How about this true life scenario? Nearly 6,000 scouts learned all about ham radio in late July – at the National Scout Jamboree. Girls and boys toured the K2BSA ham stations and made QSOs over the airwaves. A handful of lucky Jambo scouts conducted an ARISS contact with astronaut Doug Wheelock, KF5BOC, and they will never forget it throughout their entire lifetimes. Hundreds of scouts watched in awe while the ARISS contact took place. During the week of Jambo, license classes were held resulting in: 147 new Technician Class licensees, 33 new General Class licensees, and 8 new Amateur Extra Class licensees. Plus 210 scouts earned their Radio Merit badge! What a score.

Every week a similar event takes place. Every week an astronaut who is a licensed ham (licensed thanks to the ARISS Team, in particular, Kenneth Ransom) supports an ARISS event. The learning activities revolving around the ARISS QSO could be taking place at a big camporee, at a junior high school, or in a science museum where a particular elementary teacher takes his or her class once a week for exciting technology lessons. It could also happen in any elementary school, any high school class – maybe related to science, or any college or university -- maybe the engineering students.

ARISS is the Instigator

Between January 1, 2010 and August 20, 2010 (as I write this) eight US youth groups or schools have taken part in ARISS educational activities revolving around an ARISS QSO. The US is scheduled for 20% of the contacts as is Europe, Canada, Russia, and Japan. The ARISS-International worldwide team is divided into five regions that match up to the world's space agencies. The agencies are NASA, CSA, ESA, JAXA, and RSA. The matching ARISS Regions are the USA, Canada, Europe, Japan, and Russia.

The ARISS Regions also service school and youth groups in countries other than their own that are within their Amateur Radio IARU (International Amateur Radio Union) regions. For instance, Japan services schools and youth groups in Australia.

Each ARISS Region takes very seriously the objective and challenge that ARISS equals education for youth. Within each region is a wonderful cadre of dedicated ARISS Mentors who volunteer to lead each school or youth group through the ARISS QSO, and the assignment starts months in advance. The ham who steps up to the plate starts the project once the school or youth group has been put on the ARISS tentative scheduling calendar. The work ends after the QSO has taken place and the school's or youth group's NASA evaluation and NASA surveys have been submitted.

Each school or youth group has a few area hams who encourage or aid the teacher with lessons related to Amateur Radio and wireless technology. A myriad of other ARISS volunteers support everything that happens in between. In the USA, ARRL and AMSAT lead these responsibilities.

What Types of Education Outcomes Occur?

Wonderful examples of the education outcomes a school can garner from ARISS-related technology lessons, space lessons, and the radio contact were explained by the faculty at Midvalley Elementary School in Midvale, Utah. Midvalley Principal Carla Burningham knew about ARISS activities in other schools. So she hoped students in her school could have the benefit of ARISS because she wanted them to experience "real-life science" in their daily lives.

More than a year before the school's ARISS radio contact, while writing the required educational proposal to accompany the ARISS school application, Carla and sixth-grade teacher, Dave Bettinson first researched ARRL Education & Technology Program materials (see www.arrl.org/education-technology-program). Dave knew Utah fifth grade students had studied a science curriculum of basic electricity. He knew Utah sixth grade students were to learn about the electromagnetic spectrum for their science curriculum. This would be the perfect tie in to Amateur Radio and ARISS, and he could easily get ARRL lessons to support the curriculum.

ARISS education activities allowed him to use more wireless communications and Amateur Radio in his classrooms. He had already been liberally sprinkling in NASA lessons about technology onboard the International Space Station, plus some of its history.

Every state has developed required science standards for students that each school must meet each year. Dave listed the following state science standards that the ARISS studies fulfilled for the sixth graders:

- 1) Manifest Scientific Attitudes and Interests
- 2) Understand Science Concepts and Principles
- 3) Demonstrate Awareness of Social and Historical Aspects of Science
- 4) Understand the Nature of Science

To ensure his educational activities about basic electricity had follow-through after the main ARISS events were over, he used his technology lessons as a stepping off point for more in-depth science studies during the rest of the year. For many more details about this school's ARISS educational activities, please see ARRL's October 2010 issue of *QST*.

Carla, the principal, was thrilled to be able to exclaim a month after the main ARISS events that student interest in science, space, and Amateur Radio had greatly increased. She added that the ARISS contact itself was the best part of her 29 years as an educator because it inspired students so much! That's quite the statement!

Dave reported that student interest continued for months regarding ARISS, science, and technology. He said the ARISS contact would "reap rewards in science interest for years to come."

Your School

Do you know an innovative teacher who instructs classes in the sciences, technology, engineering, or math – the "STEM" classes? Or a teacher who belongs to ITEA – the International Technology and Engineering Educators Association? Or a teacher or adult leader who works with a Challenger Learning Center or science museum? Do you know a principal who is serious about STEM objectives? Do you know a school that specializes in the sciences? These are the perfect educators and institutions to talk to about ARISS.

When you talk to educators, you can cite some of the plans and some of the terrific outcomes experienced by the Midvalley Elementary School. You can show them the October 2010 *QST* article. Or you can pull facts from the following reports from schools and youth groups that had robust ARISS educational activities revolving around ARISS radio contacts of the past few months:

Riley Avenue School, Calverton NY

The Peconic ARC supported this ARISS contact. The school has many

academic ties to the Brookhaven National Lab, and many parents work there, so the ARISS educational activities supplemented the science curriculum, particularly in the third and fourth grades. Additionally, in order to involve the whole school, cross-curricular activities were part of the education plan, including a reading program of non-fiction books about space and the introduction of math problems related to space.

Walnut Creek Elementary, Azle TX

This K-4 school has a new ham radio club. Students got to operate the radios and figure out the many things that can be done with ham radio. The first event was Kid's Day with QSOs being made on HF. Students participated in hands-on mapping skills to keep track of the locations of the hams they contacted. Fourth graders (120 students) studied the Solar System, and made models of their favorite space object, researching facts about it, and writing a report they presented to other classes in the school as a part of their Space Day events. Retired Lockheed employees and members of the Tri-County Amateur Radio Club gave demonstrations on satellite communications, Sputnik model making, determination of the heat of an object traveling in space, and space station tracking.

Jessup Elementary, Houston TX

With the help of members of the Clear Lake ARC, ARISS activities were integrated into the full school curriculum involving many grades. The focus was on science, technology related to ham radio, math, and language arts instruction across kindergarten to fourth grade. A variety of instructional strategies included essay contests for older students, demonstrations of ham radio, discussions on the ARISS radio set-up and system, ham radio propagation, and kindergarten poster drawing focused on space exploration. The teachers of the gifted and talented classes planned the lessons.

Camp Cavett, Oklahoma City, OK

Camp Cavett is for youth with terrible illnesses. Classes were scheduled two periods each day using ARRL-provided lesson plans to explain some wireless technology and radio principles including line of sight versus skip, what blocks signals, reflection and refraction. We had demonstrations of HF contacts, PSK operations, and with the assistance of the FAA Aeronautical ARC, we used their repeater for UHF operations. We had discussion for 30-60 minutes, and then afterwards, hands-on operation of the radio systems. We studied why we go to space, what makes it possible to have a space station, and how it applies to youths. For students expressing interest in becoming hams, we helped them find license classes.

National Scout Jamboree, Fort AP Hill, VA

Jamboree sports 43,000 Scouts and leaders in 825 troops, plus 5,000 support staff. The K2BSA Amateur Radio Demonstration Area is a hot spot of activity throughout the Jamboree with hundreds of scouts learning about the principles of radio communications. At past Jamborees, more than 300 scouts

earned their Radio Merit Badges, more than 100 new Technician licenses were earned. And thousands of Scouts toured K2BSA.

Space Jamboree, Rantoul, IL

The Rantoul National Aviation Center is the former Chanute Air Force Base, home of the Chanute Air Museum that exhibits aviation and aerospace artifacts, and has technical training programs. The museum will host "Space Jam 4" for boy and girl scouts from 4 Midwest states. Merit Badges will be earned in Space Exploration, Radio, Aviation, and Electronics. Scouts will make their first QSO and learn about space, principles of ham radio communications and propagation, ham satellites, and related topics.

DaVinci Science Center, Allentown, PA

The center will engage students in its 200 hands-on exhibits and laboratory programs on science, technology, engineering, and math activities. NASA is providing assistance with lessons on space. The Delaware Lehigh Amateur Radio Club will provide lessons on Amateur Radio satellites, UHF modes, and SSTV.

****The Final Word****

It would have been impossible for all of this great student learning to have taken place if we did not have the terrific ARISS volunteers worldwide. And you know who you are!

The educational outcomes would have not been seen if it weren't for NASA, AMSAT, and ARRL.

Without all of these important pieces ARISS could not exist. So the final word in this paper is: THANK YOU to all of you who work so hard on the ARISS Program. You are wonderful!

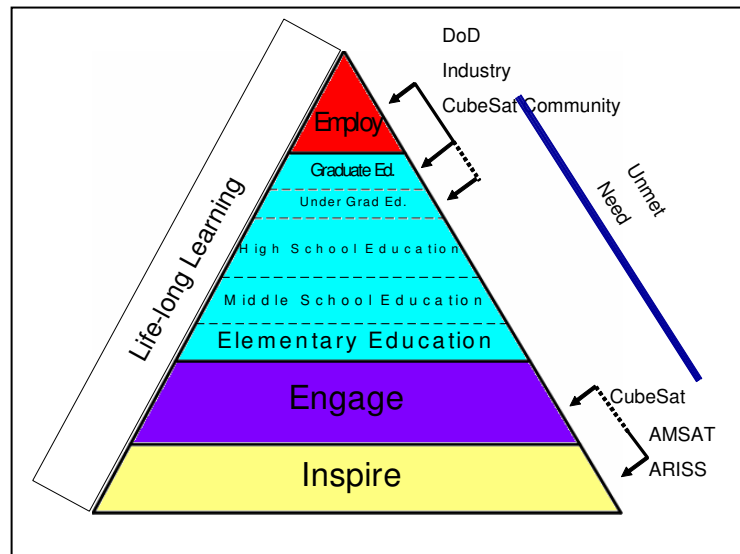
Education Paradigm Shift for AMSAT to Support Subsidized Launch Opportunities

By: Mark Spencer, WA8SME, ARRL Education and Technology Program Director
774 Eastside Rd., Coleville, CA 96107, mspencer@arrl.org, 530-495-9150

Abstract: Subsidized launch opportunities for satellites come with some hefty strings attached. To qualify for a subsidized launch, the satellite must meet a moving target of criteria that supports DoD, Industry, Education, and/or Humanitarian Relief interests. AMSAT can qualify for subsidized launch opportunities without making significant changes in the goals and mission of the organization or the proposed satellite capabilities; AMSAT only has to re-tool and re-package the organization's education theme to make it more visible and viable to the launch providers. This paper emphasizes a growing gap of un-met needs along the education continuum that are not being addressed by the satellite community. Then suggestions are presented how AMSAT, in cooperation with other Amateur Radio related interests, can address those needs and in turn leverage those efforts to qualify for subsidized rides into space.

Some background. To put the following thoughts in context, let's take a moment to reflect on education. One paradigm used to model education is a four-tiered pyramid. The base of the pyramid is Inspiration: to affect, guide, or arouse interest. The next level is Engagement: to obtain and hold attention. The meat of the pyramid is the third level, Education: to provide or facilitate gaining knowledge and training. The ultimate goal of education is reflected in the top of the pyramid, Employ: to put the knowledge gained through education to some use or service. The education pyramid represents a life-long activity that enriches lives.

The reason why we need to revisit education in the most fundamental terms is because it is through education that AMSAT will have the greatest chance to qualify for subsidized launch opportunities.



Opportunities. Recently, launch vehicle operators have offered subsidized satellite launch opportunities for the bargain price of approximately \$40K, which is basically the cost of the satellite integration into the launch vehicle...the actual ride into space is free. Of course there are restrictions. The satellites must conform to a standardized size and mass, multiples of the CubeSat standard of 1U equal to 10 centimeters cube and up to 1 kilogram in mass. The purpose or mission of the satellite also needs to conform to the interests of the supporting organization to include, but not necessarily limited to Department of Defense, Industry, Education, and most recently Humanitarian Relief interests. Within these interest areas, research in space weather and advanced technologies are just two that might gain the attention of some launch providers. However, it is doubtful that the AMSAT community shares those interests nor have the capability and/or resources to devote to space weather research or develop new and innovative advanced technologies on a grand scale (though the talent is certainly there, only bounded by fiscal realities, shallow pockets, and proclivity). The most likely areas of interest that AMSAT could address to qualify for a subsidized launch opportunity are in the areas of education and perhaps humanitarian relief.

Some shortfalls. If we look at how the satellite community is currently addressing the needs posed by the education pyramid, there clearly are some good things that are being accomplished, and probably under-advertised and appreciated; but also there are some un-met needs that can be addressed. The point of this paper is to point out that if AMSAT were to do a better job of “chest beating” those pyramid tiers that we are currently addressing, and make some minor shifts in our satellite efforts to address some of the un-met education needs, then perhaps we can leverage a revised education mission into subsidized rides into space.

The CubeSat community, primarily graduate level educational institutions, are doing some phenomenal, cutting edge things to advance space-borne technology. However, in my view, though the CubeSat community talks a good game of addressing broad educational interests, they are more program and institution focused and tend to favor post graduate students to prepare them for employment in industry. This is not a criticism, they are serving the needs of their universities and students, but they are in reality not providing very much support below the graduate level, and certainly not supporting students at the high school level and below. Criticism of this over generalization is certainly warranted however, but an objective review would prove this generalization to be pretty accurate. The danger here is that if the lower level students are not introduced to satellites and space-borne technology early in their education careers and encouraged to pursue studies in the technology, where will the future graduate students come from?

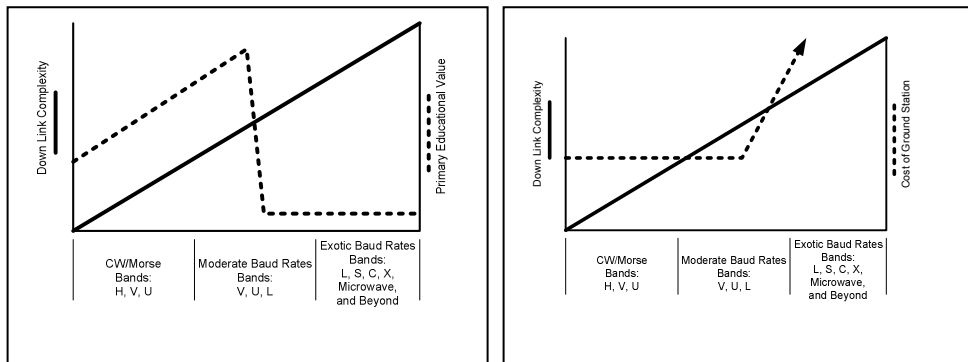
On the other end of the continuum are the AMSAT and ARISS communities. ARISS until very recently has focused on inspiration. This is evident in their program focus on dedicated school contacts that are measured as successful by the number of questions asked of the astronauts. The majority of the contacts are conducted by tele-bridge, with the ham radio element on the other side of the globe connected to the student audience via speakerphone. This is a reality of the operational constraints of the ISS mission schedule. The result is that students are insulated from the technology required to connect with the astronauts, all they see is that there is a Wizard behind the magic curtain and voices coming out of the speakerphone. There is little focus on teacher and/or student preparation before the ARISS contact and little if any follow-up after the contact. Again, criticism of this over generalization is certainly warranted, and there are shining examples of success after the inspiration of the ARISS contact, but those successes truly are rare and rarely substantive beyond the immediate media hype aftermath.

What AMSAT is doing. The AMSAT community also contributes significantly to inspiration though primarily to the life long learners that make up of the Ham Radio operator audience. Satellite demonstrations at Hamfests and school science fairs are indeed very inspirational and have some educational value.

Where AMSAT differs from the ARISS and the CubeSat communities is in regards to supporting the educational pyramid is at the tier of engagement. Once a student is inspired to look further into the study of space-borne technology, they need ample opportunities to “do” satellites, not just “witness” satellites. This requires that students can engage, to use, satellites in space on a regular basis in support of their school curriculum and private interests. The CubeSat community currently supports engagement by sending telemetry from their systems in a format and using frequencies that are within reach of a modest ground station operated with some modest skill (however this support is at risk which will be addressed later). Though ARISS has recently added engagement to their mission statement portfolio, they have not followed up the statement with actionable signal activity. Once the initial 7-minute ARISS contact is made, the ad-hoc contact opportunities with the astronauts in orbit are becoming increasing scarce, and when they are available, they are unpredictable. Other ISS based radio systems such as the cross band repeater, the APRS digipeater, or the SSTV transmissions are also rarely heard and are also random. True engagement involves access, ARISS signals and contact opportunities, for what ever reason, fall short of providing engagement opportunities that are usable in today’s classroom. On the other hand, AMSAT assets, along with the assets of the other Amateur satellite organizations across the globe ‘do’ engagement...engagement is the fundamental purpose of these satellites. The Problem is that we do not package the engagement mission using the educational vocabulary needed to articulate that mission to those outside our tight knit community.

Some missed opportunities. Returning for a moment to the CubeSat community’s engagement activities, telemetry from the portfolio of cubesats is transmitted primarily on the U band and using Morse code or sometimes Packet radio. This makes access to these signals with a modest investment in ground station equipment and modest operator skill possible (though it can be argued that the number of people fluent enough in Morse code is dwindling). However, as the CubeSat community pushes the envelope, which is the natural thing to do as technology advances are being made, this push also starts to erode away the easy and ready access to the telemetry

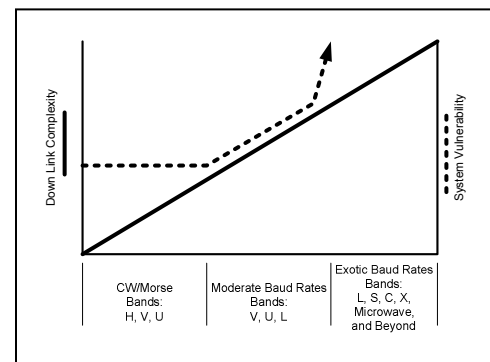
being sent from the satellites, in other words, limits the engagement potential of the systems. The following graphics illustrate the trends and consequences of the trends that I see the CubeSat community taking.



The left axis represents the increased complexity of the down link signals sending telemetry. The right axis represents the continuum of educational value, cost of the ground station equipment or system vulnerability as appropriate. The horizontal axis represents the continuum of the capabilities of the ground station needed to receive and exploit the telemetry, with rightward movement representing increasing costs.

As the on-board sensors advance, more data is collected which requires high baud rates and therefore higher frequencies to accommodate the higher data rates resulting in an increase in down link complexity and an increase in ground station costs (the solid line). Likewise, as the satellite capabilities advance, the educational value of those systems also increases up to a point as represented in the dashed line. There is a point at which the down link signals are so complex that they require ground stations that are so complex and expensive that schools cannot afford the equipment for the limited number of signals and by default because they cannot afford to access and exploit the signals, the educational utility drops.

This results in a “Catch 22” situation for the CubeSat community and makes their more advanced systems actually more vulnerable to data loss and disruptions. As mentioned, as the data link complexity increase, the station complexity increase and the number of stations available to collect the data goes down. As the number of ground stations capable of collecting the data decreases, the data rates to down load the collected data needs to increase so that the data can be accessed by the few remaining stations, within range of the satellites during the sort time available, which leads to pressure to increase data link complexity to accommodate for the lack of ground station availability...and the cycle continues. I heard an example of this situation recently during a conference presentation. The presenter lamented that there were only five stations globally capable of receiving a particular satellite’s whole orbit collection because of the amount of data collected, the low orbit, and therefore short time in range of the ground stations. The system was vulnerable because a loss of just one station results in significant loss of data collection. The proposed solution was to increase baud rates and down link frequencies (which arguably would further limit the number of stations capable of receiving the down link, and also further restricting access by potentially interested schools and students).



Need to re-focus. The answer to me at least is clear. While the CubeSat community continues to push the envelop of technology, they should keep in mind that there is a need to support the basic education community that needs engaging signals from space so that they use these signals to educate their students. So while the trend to increased down link complexity will continue, capabilities must be built into future satellite systems to provide accesses to the telemetry with affordable, and achievable ground station equipment. And while the CubeSat community supports this engagement effort, at the same time they are building some redundancy into their collection system so that one

failure of a system node is not catastrophic. I guess the question that needs to be answered is, does it make better sense to have just a handful of ground stations capable of receiving the telemetry transmitted at cutting edge rates, or have thousands of stations capable of receiving portions of the collected data transmitted at more modest rates but shared via internet? Additionally is it better for 5 institutions of higher learning alone be active participants in the system, or is it better for potentially thousands of education institutes from all grade levels as well and interested private citizens outside the formal education community be actively engaged in the system? I actually feel that we can have both.

Resources alone are not sufficient. There is one more piece of this puzzle that is not being address by the satellite community; teacher education. Teachers teach the way they were taught. Despite the movement toward teaching to specific educational standards and benchmarks, teachers tend to teach what they are most comfortable teaching. The problem is that teachers have not been taught about satellite technology, nor is it likely that they have been taught how to teach satellites. There are of course those rare student teachers, but the majority of the college students who pursue studies in satellite technology in all likelihood will not go into teaching. What this means is that while the satellite community addresses the education pyramid and tries to support the four tiers of the pyramid, there also has to be a concerted and parallel effort to “train the trainers” in satellite technology. This train the trainers effort needs to be on two fronts, one within the universities’ teacher training programs, and the other an outreach in-service training program for teachers already in the classroom.

Way forward, and up! Okay, so what? What does all this have to do with competing for subsidized rides into space for our satellites? Here are a few things that I wish the AMSAT community would consider.

We are already doing engagement, it is just that we don’t know it, and we certainly do not stress this to the other members of the satellite community to our benefit. Because we are already deeply involved in engagement, we can take a leading role in attempting to influence the rest of the satellite community to better support bringing space borne technology education into our schools. If AMSAT is recognized as the primary source of engaging space borne resources, that puts our applications for subsidized launch opportunities in a better context during the review processes that are allocating these launch grants. So now, how do we start?

First and foremost, we need to start with the fundamentals. Space borne technology has become an integral part of the fabric of our culture. If you look around where you are sitting, there are probably a number of things that depend on space borne technology, and there are many activities that you do throughout your day that also depend on satellites. If satellites and space borne technology are so important to our culture, maybe the average citizen should learn more about it...the average citizen should have some level of space literacy. To start, AMSAT should define what space literacy is, “what does the average citizen need to know about space and space borne technology to be productive citizens of this country, and to use that technology to enrich their lives.” The definition of space literacy then becomes the compass for follow-on activities.

Second, based on the definition of space literacy, AMSAT should develop plans for our future satellites that support space literacy. That is not as difficult or as limiting as it first might appear. The AMSAT community has focus groups of enthusiasts that are promoting systems that meet their literacy (interest) needs whether it is HEO, LEO, FM, analog, digital or what ever birds, they all make up the overall concept of our vision of space literacy. But, and this is a big caveat, the planning for future systems needs to also be based on current (and projected) realities. Subsidized launch opportunities are most likely to be LEO orbits with an inclination that may not be ideal...in other words, you take what you can get. Also, launch opportunities will probably not be made available years in advance, more likely they will be made available to those organizations that have “shovel ready” satellites that are ready to go when the launch is scheduled. This will probably dictate systems that have more generic capabilities, less specialized or cutting edge, and inexpensive enough to be built and shelved ready to go.

Third, continue to support education and advancement of satellites among the Amateur Radio community but “double dip” that effort by leading the way in developing a standardized, affordable, and capable ground station to access satellites. If the Amateur Satellite community is fluent in the acquisition, set-up, and operation of a standardized ground station, then there will be thousands of trained trainers that can assist others, and local schools and teachers to set-up stations in their institutes and gain access to satellites.

Fourth, the proliferation of a standardized ground stations might encourage the CubeSat community to “dumb down” their data links (a poor choice of words, but reflecting the intended meaning) to allow more accesses to the signals and encourage more students outside the immediate project audience, and Radio Amateurs to participate and support the system’s telemetry collection effort while making their system less vulnerable to single point failures.

Fifth, if the standardized ground stations are readily available, easily replicated, and are affordable, perhaps more teachers will be encouraged to integrate space technologies into their curriculum. This will generate the need for teacher training. While AMSAT can not expect to run a teacher in-serve training effort, the AMSAT community certainly can support other teacher in-service training efforts such as the ARRL’s Education and Technology Program Teachers Institutes. The grant programs can provide the resources for teacher training as well as the procurement of the ground station equipment making space in the classroom very affordable for schools. Grantors however will not throw money at good intentions. There has to be a reasonable expectation of success and return on their investment. Trained and supported teachers leading a school program initiative goes a long way in showing potential of success. AMSAT members can provide invaluable support to their local schools by mentoring teachers and school programs and provide some traction where the granted monies, resources, and training meet the road. This kind of support provides some depth to a school program that Grantors can appreciate.

And finally, if AMSAT were to pursue these five efforts, the educational mission of AMSAT will have expanded from the obvious Inspiration tier alone to include the Engagement tier that we have already been doing unobtrusively, and delve deeply and head-on into supporting the Education tier. These credentials would then have some substance and specifics that lend themselves to flesh out a very competitive application for a subsidized launch.

AMATEUR RADIO on the ISS

Operations Update – 2009-2010

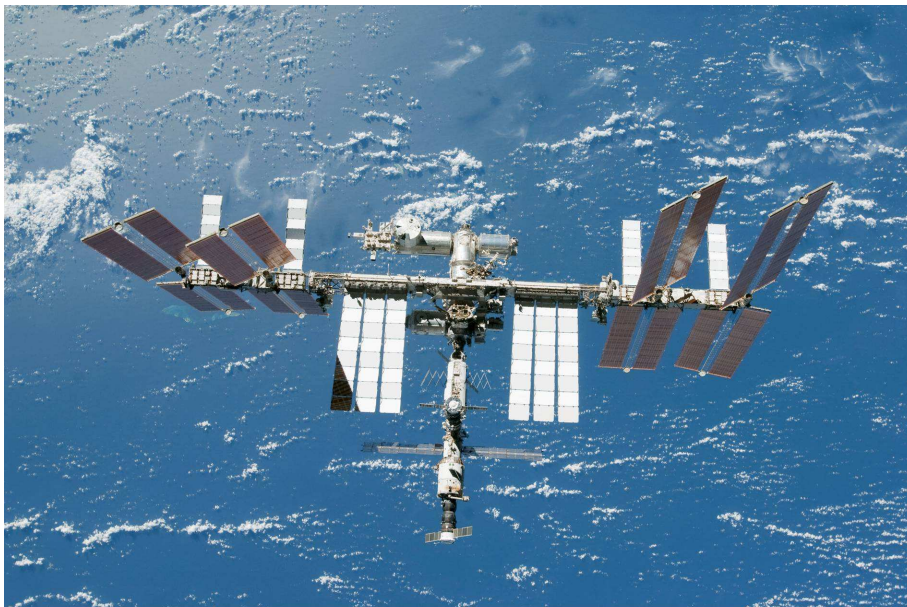
By
Keith Pugh, W5IU

Purpose and Objectives of ARISS –

The primary purpose of Amateur Radio on the ISS (ARISS) is to promote education of our youth in math, the sciences, engineering, and technology through exposure to the International Space Station (ISS) Program. A secondary purpose is to expose students and others to the world of Amateur Radio and the many benefits of this fascinating avocation.

Working with professional educators worldwide and with the Space Agencies of the world, ARISS provides opportunities for students of all ages to talk and exchange ideas with Astronauts on board the International Space Station (ISS) while in orbit. Amateur Radio provides the media for this exchange to occur and the volunteers that facilitate the primary purpose.

ISS NOW COMPLETE – Hosting 3-6 Person Crew Operations



S130E012100

ARISS Organization –

Based on the legacy of Human Spaceflight dating back to 1983 and Owen Garriott's STS-9 flight, including the Shuttle Amateur Radio Experiment (SAREX), and MIR, ARISS was formed in 1996. Founders were Roy Neal (SK), K6DUE; Frank Bauer, KA3HDO; Rosalie White, K1STO; and Matt Bordelon, KC5BTL. The team is governed by a group of ARISS International Working Group delegates from Canada, Europe, Japan, Russia, and the USA. Delegates are chosen from the Radio Amateur Satellite Corporations (AMSATs) of the world, the National Amateur Radio Organizations (such as ARRL), and the Space Agencies of the world. These delegates meet via monthly telephone conferences, and about once a year in face-to-face meetings (Moscow in 2008, the Netherlands in 2009, and tentatively in the US in 2011). In between, activities are coordinated by e-mail and additional telephone conferences as necessary. These delegates set the policy (with advice from the space agencies) for operation, coordinate equipment for the ISS, coordinate with education organizations, coordinate school selection for contacts, and provide oversight to the ARISS Operations Team – the other major ARISS group.

With the resignation of Frank Bauer, KA3HDO, last year, ARISS was left without a delegate from AMSAT-NA and had to elect a new ARISS International Chairperson. Will Marchant, KC6ROL, filled the AMSAT-US delegate role for a while, and Gaston Bertels, ON4WF, is the new ARISS-I Chair. Will Marchant resigned and Barry Baines, WD4ASW, President of AMSAT-NA, served until Dave Taylor, W8AAS, was appointed to the AMSAT-US slot recently. In a separate action, Maurice-Andre Vigneault, VE3VIG, became the ARISS-Ca Delegate representing AMSAT-Canada.

ARISS Operations Team

The ARISS Operations Team is made up of ARISS Mentors, scheduling/technical representatives, and an orbital prediction specialist. An ARISS Operations Lead is selected from within the ranks on a periodic basis. This group meets weekly by telephone conference and much more frequently via e-mail and telephone. ARISS Mentors are the volunteers that work with the schools, teachers, and local Amateur Radio groups that actually make the contacts with the ISS. Scheduling/technical representatives work within the space agencies, primarily NASA in the USA and the Russian Space Agency to secure the final schedules for the contacts. These scheduling representatives also coordinate training of the Astronauts in the use of the equipment on board the ISS and procedures for its use. The orbital prediction specialist does the long and short term predictions necessary to support the scheduling of all of the contacts. I will talk more about these functions and their relationships with each other in subsequent paragraphs outlining the scheduling and performance of the contacts.

School Contacts this Year –

The past twelve months (15 Sept. 2009 thru 14 Sept. 2010) have yielded 78 School Contacts involving 13 Astronauts from Expeditions 19 to 24.

<u>Expedition</u>	<u>Astronaut</u>	<u>Callsign</u>
24	Doug Wheelock	KF5BOC
24	Shannon Walker	KD5DXB
23	Mikhail Korniyenko	RN3BF
23	Tracy Caldwell-Dyson	KF5DBF
22	Timothy Creamer	KC5WKI
22	Soichi Noguchi	KD5TVP
22	Oleg Kotov	RS0ISS
22	Maxim Suraev	RS0ISS
21	Jeffrey Williams	KD5TVQ
21	Nichole Stott	KE5GJN
20	Frank De Winne	ON1DWN
20	Robert Thirsk	VA3CSA
19	Michael Barratt	KD5MIJ

These Astronauts hail from several countries such as: US, Canada, Russia, Japan, and Belgium. They are all multi-lingual but they are most popular within their own region of the Earth. If the contact cannot be arranged with a native speaker, English is usually the default. Several of these Astronauts are pictured below.

Expedition 24 Crew



Expedition 22 Crew



EXPEDITIONS 20 & 21 CREW



The contacts can be broken down into the Regions or Countries involved as follows: US (13), Canada (13), Europe (25), Russia (4), Japan (11), Australia (6), Africa (2), Taiwan (1), Malaysia (1), Peru (1), and Brazil (1). Within Europe the countries involved were: Italy, France, Germany, Poland, Belgium, Netherlands, Portugal, Norway, and Greece.

For about half of this year, we have been limited to one contact a week due to workload on the ISS and willingness of the crew to participate. School Contacts are the most numerous. An example from the past year is shown below.

Walnut Creek Elementary – *Calling and Listening!*



Student participation at the schools ranges from Kindergarten to University level.

During the summer months and at vacation times, a number of contacts have been made with Summer Camps, Scout Groups, Astronomy Groups, Museums, etc. As usual, the student reactions to the contacts are the reward for all of the effort expended by Teachers, Ham Radio Volunteers, and ARISS Volunteers.

Girl Guides of Canada





ARISS Operations –

ARISS Operations have not changed in the past year but are included here for a complete story.

The wheels start rolling for a school contact with the submission of an ARISS Application for an ISS contact. The latest application form is available at: <http://www.ariss.org> Ideally, a teacher hears about the possibility of a contact through professional societies, from other teachers, from Amateur Radio Operators within the community, or by many other routes. The teacher, with the help of local Amateur Radio Operators, fills out the multiple-part application and submits it to the regional ARISS organization. The regional organization reviews the application, obtains clarification if necessary, ensures the application is forwarded to the ARISS international education committee, and enters it into the list of applicants in the order in which it was received. A separate list is maintained for each region of the world and candidates are picked from each region in proportion to the number of applicants in the list. Another list is maintained for “Crew Pick” contacts. These contacts are with schools that are picked by the Astronauts for their own reasons and are usually separate from the main list. Astronauts are allocated “Crew Pick” contacts based on their interest in the program and willingness to support contacts from the main list. The main list can be quite long and the waiting period can be correspondingly lengthy. Currently, the wait for US applicants is about one year. Every effort is made to keep the wait to a minimum, but contacts are generally limited to somewhere

between one and four a week period depending upon the crew's willingness to support contacts and the workload on the ISS

Another factor to consider is whether the contact is to be "direct" or via "telebridge." For a "direct" contact, a ground station is set up at the school and the contact proceeds directly through that station with the station on-board the ISS. For a "telebridge" contact, the ground station is located remotely (possibly half way around the world) from the school and the ground station is connected to the school and other elements through a telephone conference bridge. ARISS OPS has developed and maintains a list of acceptable telebridge stations around the world (these are currently in the mainland US, Hawaii, Australia, Argentina, Belgium, and South Africa).

The school expresses a preference for the type of contact in their application and ARISS Ops will honor this preference whenever possible. A "telebridge" contact requires much less equipment at the school and is much more flexible on timing of the contact than a "direct" contact; however, it actually requires more coordination on the part of ARISS Ops to carry out. A list of requirements for each contact follows:

1. The ground station must be within the footprint of the ISS during the time of the contact and the ISS should have a peak elevation at the ground station of more than about 15 degrees. Higher passes are more desirable to maximize the contact time and minimize effects of local obstructions on the contact.
2. The pass selected must occur during normal school hours as stated on the application or within an acceptable alternate time.
3. The pass time selected must be within the crew's normal off duty but awake time. Exceptions must be approved by the Space Agency Medical Personnel. Crew sleep periods are normally fixed, but can be "sleep shifted" during special work periods that coincide with Space Shuttle or other activities.
4. Last, but one of the most important steps is this: the teacher must submit the ARISS evaluation, plus the NASA teacher surveys and student surveys. Congress has really been pushing NASA to demonstrate the value of the investment in education, and the only way to accomplish that is through feedback obtained through the surveys and evaluations. If it weren't for these surveys and evaluations, the ARISS Program could not continue to be funded by NASA and we could very well lose our capabilities on the ISS.

Picking and approving passes that satisfy the above requirements involve several steps that are outlined below:

1. A list of possible contacts is selected from the prioritized list of contacts maintained by ARISS over a period of time (usually for an ISS Expedition).

2. ARISS Mentors are assigned to each school as soon as possible. The ARISS Mentor establishes contact with the school and local ham volunteers, and verifies the content of the application (many times things have changed at the school since the original application was prepared).
3. The list of candidates is broken up into “direct” vs. “telebridge” contacts.
4. Direct candidates are submitted to the orbital prediction specialist for processing into the “best weeks” list. “Best weeks” are long term predictions that will permit selection of schools that have passes within a certain time frame that satisfy all of the nominal contact requirements above. A school may have several different “best weeks” within the overall time frame.
5. Selections are made based on contact priority and “best weeks” for each school and the ARISS Mentors obtain preferences for the available weeks from each school.
6. The ARISS Mentor continues the dialog with the school to firm up the requirements for the station, answer questions from the teacher and the local Amateur Radio Operators, assist the teacher with resources for lesson plans and in solicitation of questions and names from the students, and obtain a short description of the school and its activities for forwarding to the Astronauts. The ARISS Mentor also prepares the school for filling out a post contact survey for ARISS and NASA.
7. At about four or five weeks before the week selected for a school, detailed pass predictions for the contact are requested from the orbital prediction specialist. These predictions are verified by the ARISS Ops Lead and sent to the ARISS Mentor for forwarding to the school for prioritization within their own school schedule. The passes are ranked #1 through #n by the school and the local Amateur Radio Operators and sent back to ARISS Ops.
8. At this point, the pass ranking, student names, questions, and school description are passed on to the NASA planners by the ARISS scheduling representative for final determination of the selected pass. Usually this final pass time is available one to two weeks before the contact. In the case of Russian contacts, a similar process is performed with the Russian Space Agency.
9. Before the contact time, a final uplink message is sent to the Astronaut containing the time, station callsigns, frequency information, the school description, and the student’s questions, along with their first names, in the order the questions are expected to be asked.
10. At this point, the contact is ready to go from a planning standpoint.

For telebridge contacts this process is modified somewhat. Telebridge contacts are usually fitted into the schedule between the “best weeks” for direct contacts or are scheduled during special times that are specified by the school or event and agreed to by ARISS Ops. Telebridge contacts are usually reserved for schools that either have time requirements that are not flexible or have some

issue that will not allow for a direct contact. The modified steps for a telebridge contact follow:

1. Telebridge contacts are prioritized by the same process as direct contacts, but they are usually done when direct contacts are not possible.
2. For telebridge contacts, the orbital prediction specialist prepares a list of the passes for each telebridge station that can support a contact during the dates/time frames requested by the school and within crew constraints. This list can contain many passes and can include multiple stations.
3. The ARISS Lead pares down the list when possible and sends the remaining passes to all of the telebridge stations that have passes on the list for verification of support.
4. The ARISS Lead receives the responses from the telebridge stations and prepares a list of available passes for further prioritization by the school. This list is sent to the ARISS Mentor and he forwards this list on to the school.
5. Once the prioritized list is returned by the school, the process continues in much the same manner as for a direct contact.
6. One other step is added – a Contact Moderator is selected by the ARISS Lead to oversee final readiness verification at the school and at the telebridge station. The Moderator also makes sure school personnel and any audience is aware of how the contact will be done and the Amateur Radio involvement in the contact. A Moderator is added since many times the level of expertise at the school during the contact is less than it would be during a direct contact.
7. At the appropriate time, the Moderator turns control over to the telebridge station to establish contact with the ISS.
8. Control is then maintained by the telebridge station operator and the school contact supervisor until the pass is over.
9. The Moderator then completes the process with a closing statement.

In recent years, ARISS has succeeded in including distribution of the audio from the contact over the internet by utilizing EchoLink and IRLP. These are two methods of including many more listeners worldwide in the distribution. Doing this with a telebridge contact is relatively easy. With a direct contact it is a little more difficult, but recently success has been achieved by feeding the audio into a PC at the school and utilizing Skype (an internet telephone) to forward the resulting information to the operator that completes the conversion to EchoLink or IRLP. These operations are also carried out by ARISS volunteers.

The last thing that happens in an ARISS Contact is the enthusiastic response of the school kids, and their increased interest in science and ham radio when the contact is successfully completed. This is the pay the volunteers cherish for their efforts and is the reason we eagerly volunteer for this duty.

Plans for the Future –

SuitSat-2 now ARISSat-1

Since the deployment of SuitSat-1 and the “stir” it created, ARISS has been working on SuitSat-2. One major change has occurred: the Russian Orlan Space Suit that was to house the remainder of the satellite has been discarded early to make more space available on the ISS. ARISS was able to retain up-mass allocation for the equipment and a reservation for launch during an EVA, but we had to “shift gears” and come up with a new housing for the equipment. This task is well underway. Due to this change, the satellite has been re-named ARISSat-1. It will continue to be called RadioSkaf in Russia and on the documentation. This year has been very productive in this effort and the hardware/software will be ready for shipment to Russia by years end. Launch should occur in the spring of 2011. Details of ARISSat-1 are spelled out in other papers.

Columbus Module

The European Space Agency (ESA) Columbus Module was installed on the ISS last year along with the Amateur Radio Microwave Antennas (L and S Band) developed for it. Work continues defining the nature of equipment being developed for eventual use within the Columbus Module. Meanwhile, a dual band (VHF/UHF) antenna has been installed on the Columbus Module. First usage of this new antenna will be with the Ericsson Hand Helds (Phase 1 Hardware) that are currently on station to support expanded Amateur Radio Activity from the Columbus Module. Other required equipment has been shipped to the ISS and operations from the Columbus Module should begin in early 2011.

Project Selection and Use Committee

ARISS maintains a Project Selection and Use Committee to receive, process, and prioritize new proposals for ARISS Projects. Currently, this committee is working on plans for the L and S band equipment for the Columbus Module and for support of the current Phase 1 and Phase 2 hardware. This includes providing power supplies and cables to support radio operation in multiple locations on the ISS and eliminating the dependence upon batteries for the VC-H1 SSTV unit. If you have suggestions for projects, please document them and submit them for action.

Summary –

ARISS is alive and well. Now that the ISS is fully populated with a six person crew, expect more activity than ever before. Support this expanded activity by getting out the word to the world and volunteering your time and experience in support of all of the activity. Help bring forth new generations of people with an

expanded knowledge of science, space, and technology – if we don't, who will be interested in and be members of AMSAT in 20 years?

University of Louisiana Satellite Program
Nick Pugh, K5QXJ
ULCAPE.org



Abstract:

This presentation will update the satellite community on the ongoing satellite and related programs at the University of Louisiana Lafayette. Included in this presentation will be the mission statement, the outreach programs of the university to recruit more and brighter students, and details on its' upcoming satellite CAPE II Project. This presentation will describe how AMSAT can help the university and AMSAT in meeting its' stated goals in enticing middle and high school students into pursuing math and science careers.

Soap Box:

At every opportunity the author spends a little time to remind the audience that the third world country of Taiwan graduates more science, math, and engineering students than the US. It is the author's opinion that this has far reaching consequences for those of us that are depending on social security and those of us that would like our kids to have US based jobs. For most of us in AMSAT the pressures of raising a family and pursuing careers are easing up a bit and we have time and energy to help light the spark in the next generation to find the likes of Joe Taylor, Jostlin Bell, Tom Clark and Bob McGuire. So let's go teach our kids to build something.

University of Louisiana:

The University of Louisiana Lafayette is located in Lafayette, Louisiana which lies 100 miles west of where Hurricane Katrina hit, 100 miles east of where Hurricane Ike hit and 100 miles northwest of the BP oil spill. That's the bad news; but the good news is the University is alive and well and actively pursuing satellite programs. The university is an engineering school and the primary mission of the program is to give the undergraduates the opportunity to transition from students to productive engineers by hands on experience of designing, building, launching, and operating satellites. The secondary mission of the program is to use this as a recruiting tool to attract the best and brightest students to attend the university.

Balloon Project:

To bring the new satellite members up to speed they are assigned to a high altitude balloon project. They are given the project to design a payload that will fly into near space approximately 100,000 feet. The advantages of a balloon project are:

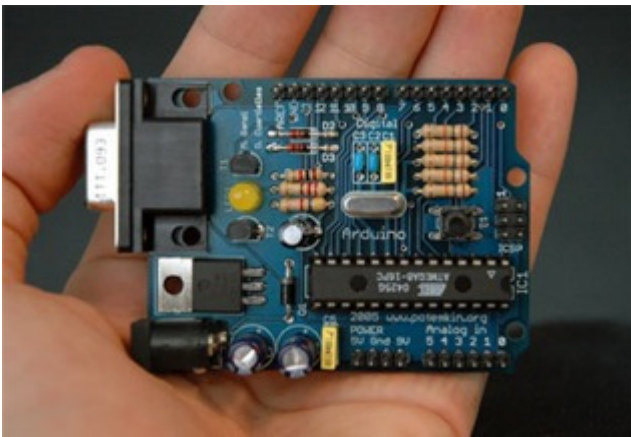
1. It is a low cost project
2. Should last about one semester
3. Far less complex of a project than a satellite
4. Has some of the design issues of deep space
 - a. Harsh environment approximately -50 deg C
 - b. Near vacuum
 - c. Requires communications system
 - d. Designed with low power consumption
 - e. Measure and control house keeping data
 - f. Data collection and interpretation of data
 - g. Multiple processors operating in real time over noisy communications channels.
5. Good educational out reach.

On the last mission the payload included APRS packets on 144.39 MHz, typical cameras and some temperature and pressure sensors. Also included were 50 of Bob Twiggs pearl sats. The pearl sats are ping pong balls that are cut in two and middle school students place bugs, plants, candy and anything else except explosives, then glued back together with a straw in the middle (see picture). These objects are flown up to altitude and if we are lucky enough to recover the balloon, will be returned to the classroom for post flight investigating.

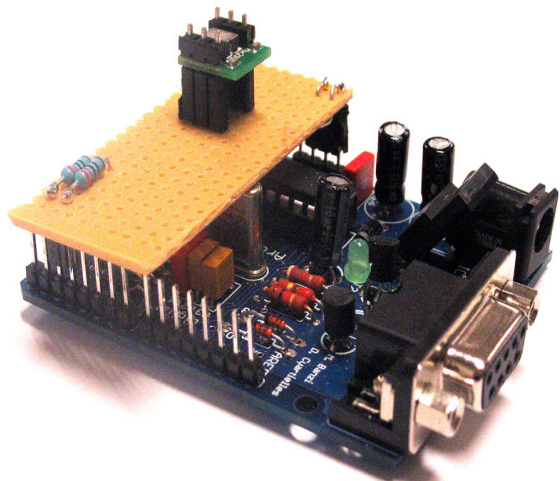
On our next mission we will fly the pearl sats and have room for science payloads from high school students. This science package can be fabricated from a small controller produced by Arduino. The cost of this device is < \$20. The sensors, like pressure acceleration, can be purchased from Spark Fun for nominal amounts. The balloon buss will collect their data and relay it to the ground archived and put on the internet in real time. (See pictures).



Bob Twiggs Pearl Sats



Arduino Imbedded Micro Controller

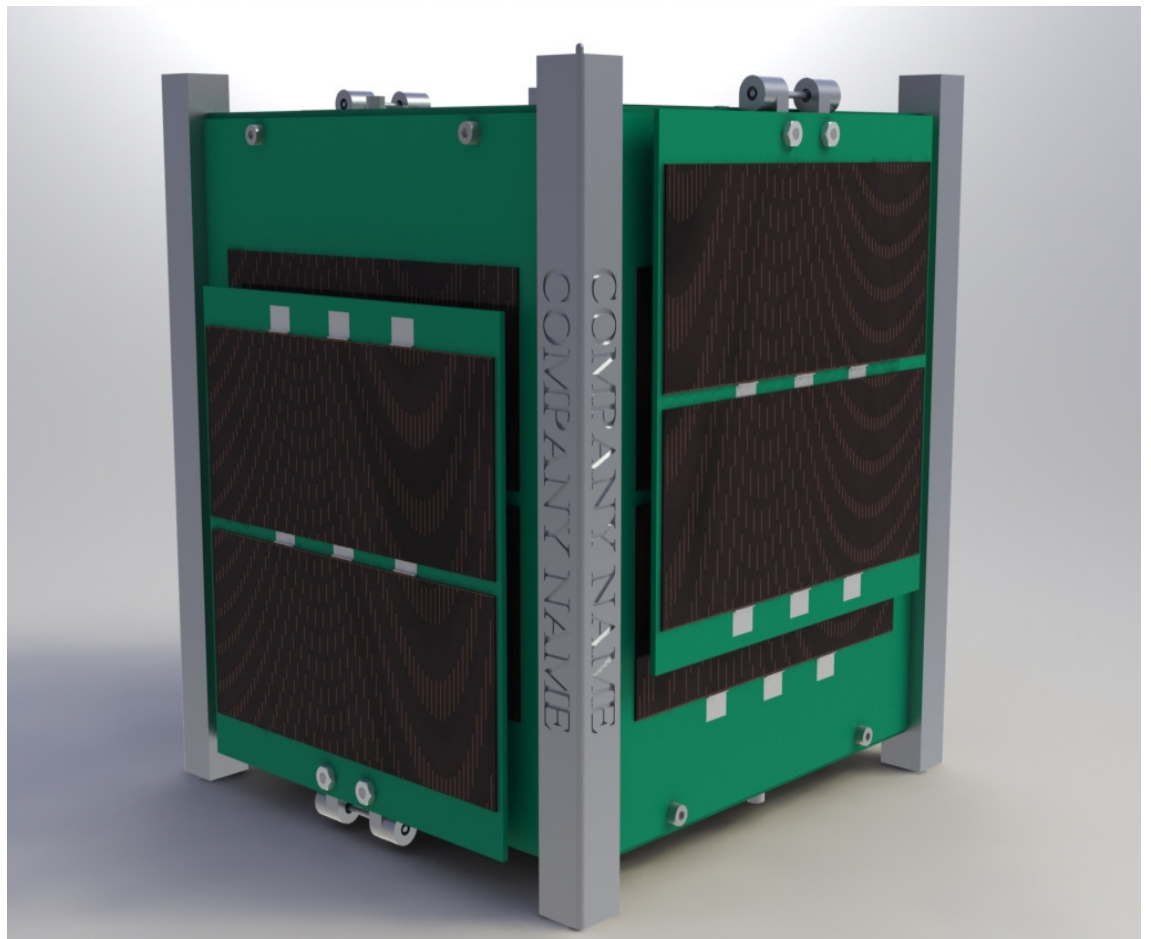


Arduino with accelerometer

CAPE II Satellite: url: www.ulcape.org

CAPE is an acronym for Cajun Advanced Pico Satellite Experiment. This is the second 1U cube satellite designed by the university. Its predecessor flew in April of 2007. The new satellite will incorporate the following new features:

1. Deployable solar panels (see picture)
2. Fault tolerant onboard computer for control and data handling
3. Two watt VHF radio on 145.825 MHz ax.25 protocols
4. One watt UHF radio on 437.225 MHz 38.4 KBS GMSK modulation
5. A SDR radio
6. APRS digi with AX.25 protocol
7. Educational payload
 - a. Parrot Repeater
 - b. Text to speech module
 - c. Touch tone encoder and decoder



CAPE II with deployable solar panels

Educational Payload:

This satellite will join a fleet of satellites like KySat, Fox and Fund cube which have similar payloads. The CAPE team has designed this payload to put the WOW factor into science classes in our secondary and primary classes. The CAPE team will design and manufacture very inexpensive ground receivers and antennas so that any class can own and operate a ground station data collection unit. The target price for this hardware is under \$50.

On any given orbit any students with the receiver, antenna and a laptop will be able to decode the house keeping data being broadcast to the ground. The teacher can email text to our ground station at the university and upload and broadcast message. Like “bon jour from Paul Middle School in Lafayette, La”. The beacon will also broadcast some of the house keeping data in plain speech like, “the temperature on my X solar panel is 30 deg C.”

If a licensed amateur is present then they will have the ability to activate the parrot repeater and upload 15 seconds of voice that will be parroted back. The amateur will be able through simple touch tone commands to interrogate the house keeping data that is being collected.

The CAPE team has designed and tested a free floating buoy that will measure sea parameters like water and air temperature, barometric pressure, salinity, wind velocity and direction. This communication to the satellite will be in APRS format on 145.825 Mhz. The buoy prototype has been tested with PCSAT I and the ISS digipeater.

This floating buoy will also be an opportunity for our young students to learn about the environment and data collection.. Following this buoy will encourage them to learn about the effects of tides, currents and wind on objects floating in the sea. They will also be able to study water salinity as the buoy drifts in the ocean.



Student with handheld radio and Yagi

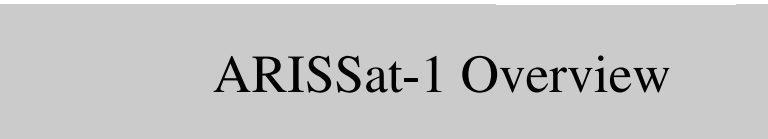
AMSAT Contribution:

The CAPE team is soliciting help from the community to be mentors to the schools in your area. To make this satellite have a real impact the CAPE team needs volunteers to be mentors to the teachers at schools near you. The teacher will need help in setting up the ground stations and help setting up the software to collect the data. For those who hold technician license or above you will be able to command the satellite uploading the text to speech payload or uplink to the parrot repeater. The up hardware to command the satellite will be a simple two meter hand held transmitter, 3 element yagi and a laptop computer. The most valuable things you bring to the project are your passion to science and your knowledge of satellites and communications systems. For those of you that have an interest in participating in this project, you are encouraged to contact the CAPE team at K5QXJ@amsat.org

As a closing suggestion for the ageing AMSATERS as we journey to the final orbit. Why not go out in a blaze of glory by discovering the next generation of inventors and builders and light the internal fires that will make them very productive citizens. This activity, in the authors opinion, not only keeps us young and healthy but is also fun.

AMSAT's Satellites

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ARISSat-1 Overview



ARISSat-1 Team Space Symposium 2010



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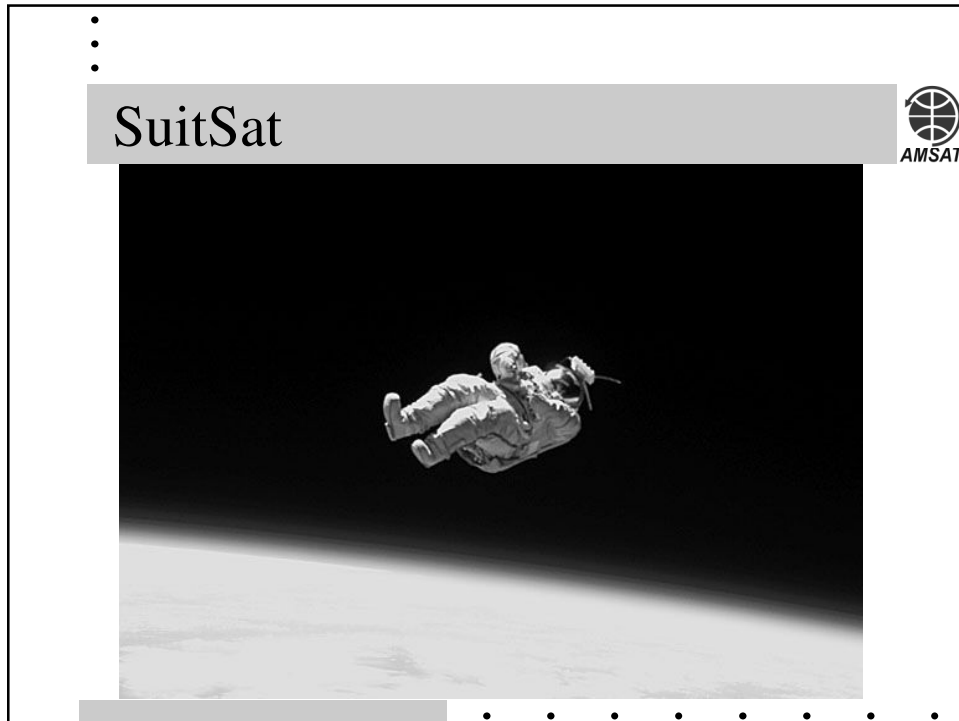
ARISS



- Amateur Radio on the International Space Station
- International organization that coordinates the amateur radio activities on the ISS
- Primary mission is education (STEM)



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ARISSat-1



- Originally planned as SuitSat-2
- Significantly upgraded electronics
- Whoops! Orlan #27 discarded due to lack of “space” on station
- New space frame developed to house electronic modules
- Renamed ARISSat-1

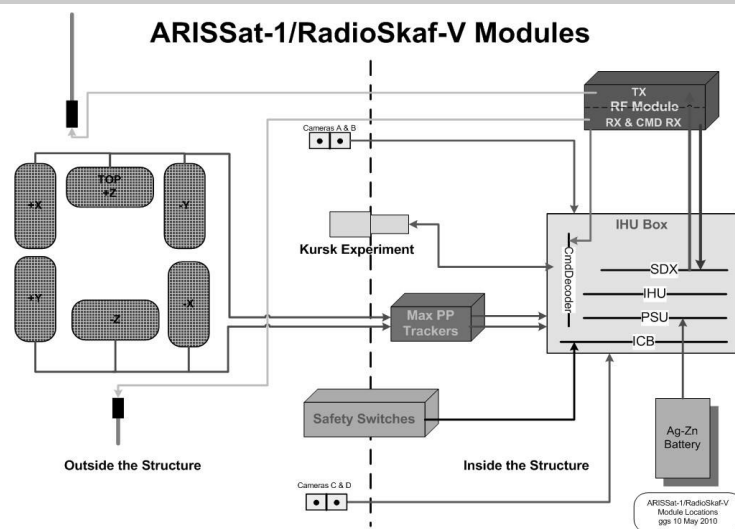
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System Modules



- Solar panels
- Max Power Point Trackers
- Battery
- Control Panel
- SSTV Cameras
- Kursk Experiment
- RF Transceiver
- Internal Housekeeping Unit (IHU)

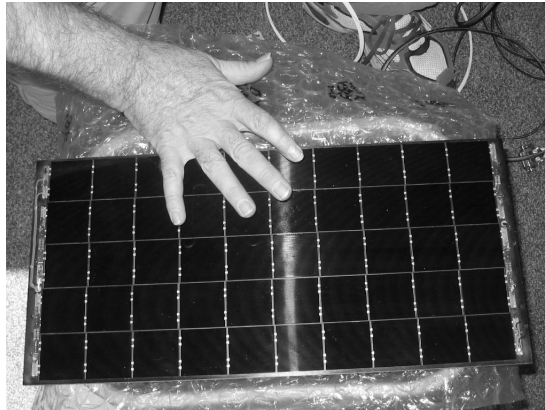
System Diagram



SMEX Solar Panel



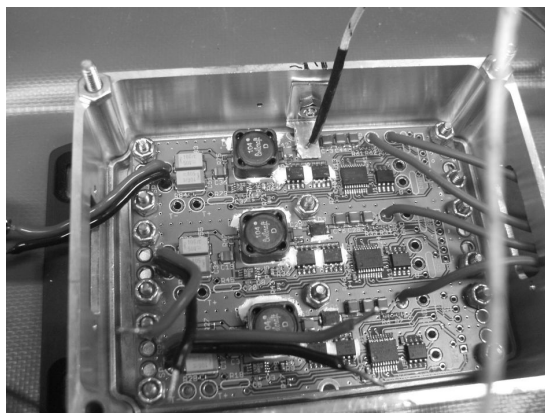
- 6 solar panels
- 19" x 10.5"
- 19 watts each
- Donated by NASA (from SMEX project)



Max Power Point Trackers



- DC to DC Power Converters
- 1 per solar panel
- Extract max power from solar panels



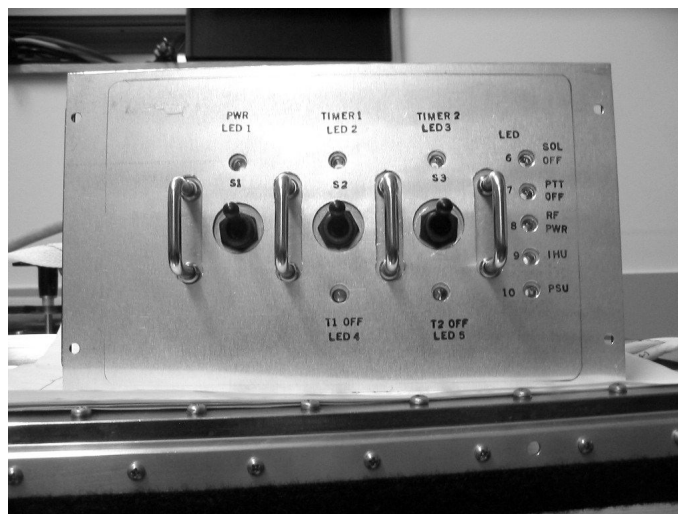
Battery



- 825M3 Orlan Space Suit Battery
- 18 AgZn cells
- Rechargeable
- 28 Volts



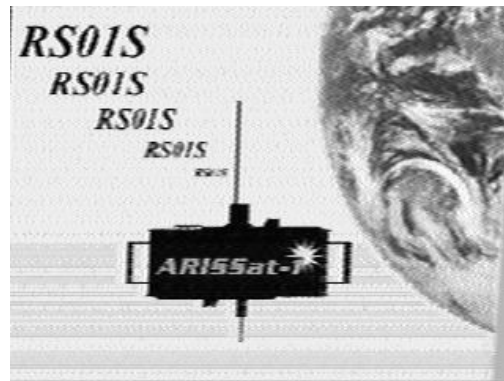
Control Panel



SSTV Cameras



- 4 cameras
- Mirrors to point in 4 different directions
- Transmitted as FM audio
- Robot-36 format



Kursk Experiment



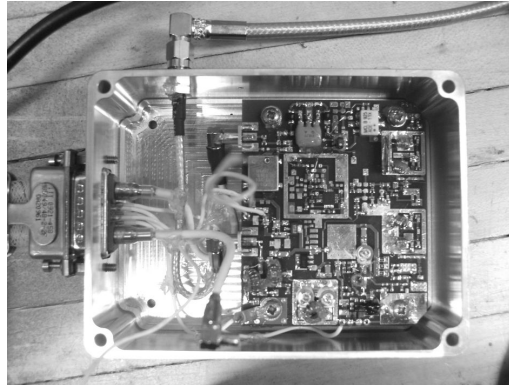
- Developed by students at the Kursk State University
- Measures the vacuum of space
- On for 1 orbit every 24 hours



RF Transceiver



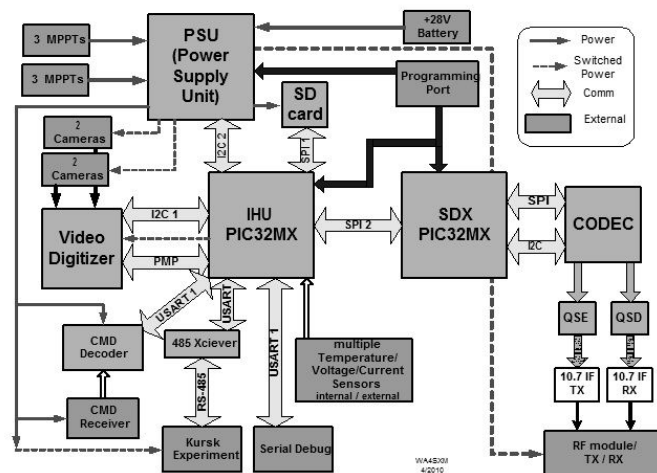
- I/O at 10.7 MHz
- Linear 2m Tx
- Linear 70cm Rx
- Command Rx



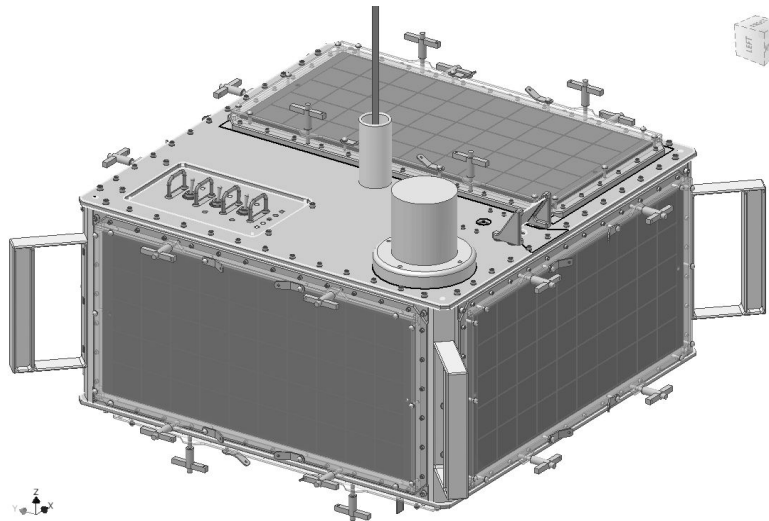
IHU Module



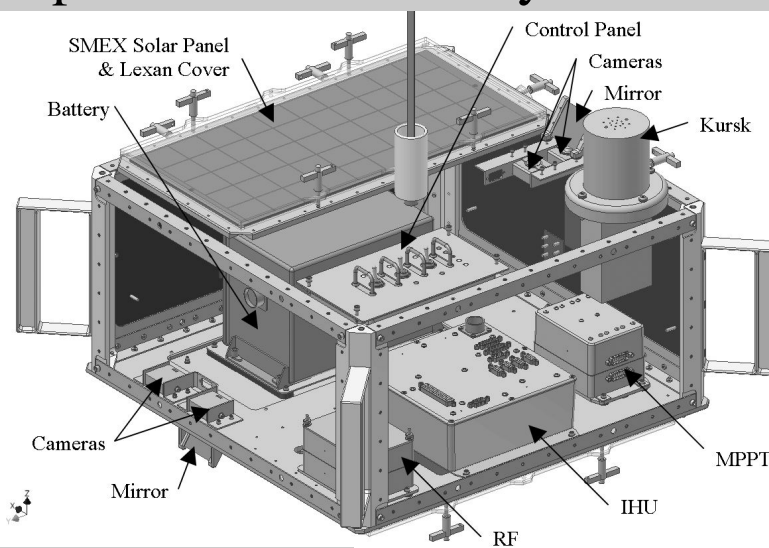
ARISSat-1 IHU Module Diagram



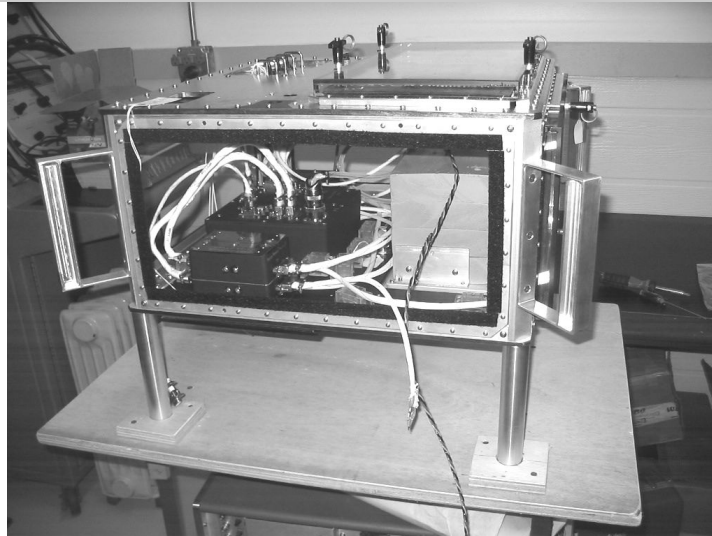
Space Frame



Space Frame Cutaway



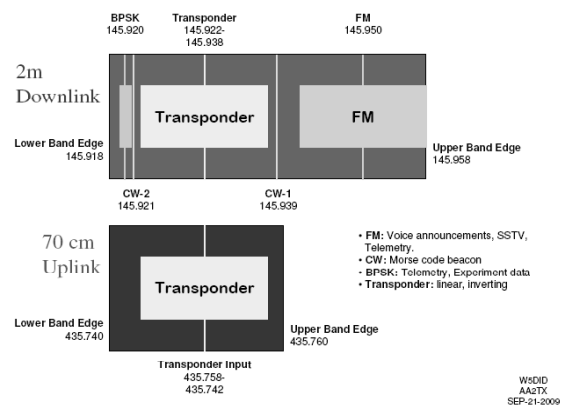
Flight Unit



RF Band Plan



ARISSat-1 Band Plan



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Transponder



- Mode V/U (70 cm Up, 2m Down)
- Linear
- Inverting (Tx LSB, Rx USB)
- 16 kHz bandwidth
- Can be worked with QRP transmitter and omni antennas

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Digital Beacon



- BPSK-1000 w/FEC by Phil Karn KA9Q
- Legacy mode 400 BPSK (P3 type)
- Telemetry Data
- Experiment Data
- PC/Mac demodulator & decoder software

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CW Beacon



- Call sign = RS01S
- CW Telemetry (subset)
- Call signs or names of developers
- CW1 or CW2 identifies BPSK mode

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FM Audio



- Call sign = RS01S
- Voice Telemetry (subset)
- SSTV in Robot-36 format
- Voice Greetings

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Voice Greetings



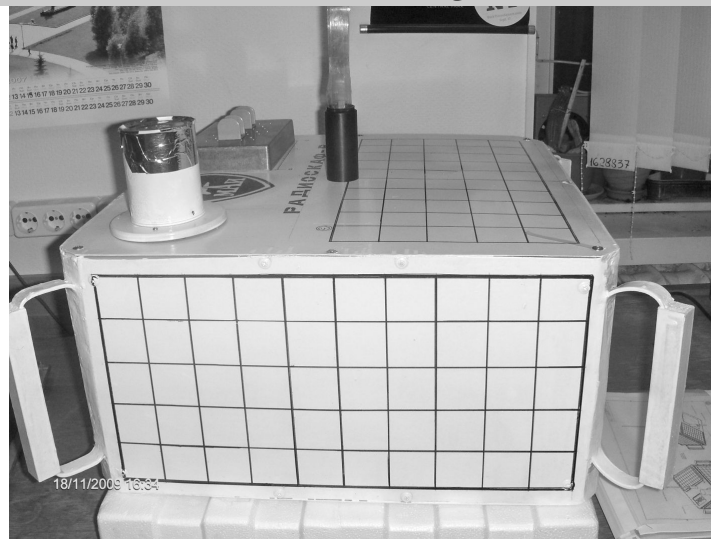
- 24 different greetings
- Mostly children
- Special one from Yuri Gagarin
- Secret word
- 15 different languages

English	Spanish	Russian	French
Italian	Dutch	Swedish	Japanese
Chinese	Catalan	Bengali	Portuguese
Hebrew	Nepalese	German	

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Cosmonaut Training - Video



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ARISSat-1 Launch



- Progress #41 launch to ISS scheduled for January 2011
- Deployment by cosmonauts from the ISS scheduled for February 2011
- Reentry in about 1 year

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Any Questions?





Thank You!



ARISSat-1 Team
Space Symposium 2010

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Software Radio Technology on ARISSat-1



Tony Monteiro, AA2TX
Space Symposium 2010

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ARISSat-1



- First AMSAT satellite to use software radios
- All transmitted signals generated in software
- Software linear transponder

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SDX



- Functionality
- Hardware Architecture
- Software Architecture
- Digital Signal Processing

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RF Signals

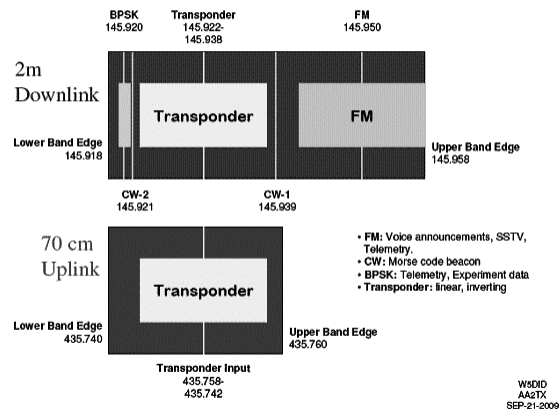


- CW Beacon
- FM Audio Downlink
- BPSK Digital Beacon
- Linear Transponder

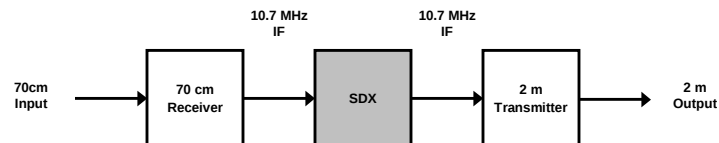
RF Band Plan



ARISSat-1 Band Plan



ARISSat-1 Radio Architecture

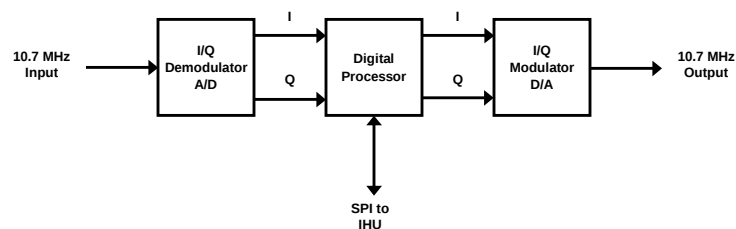


IF Translations

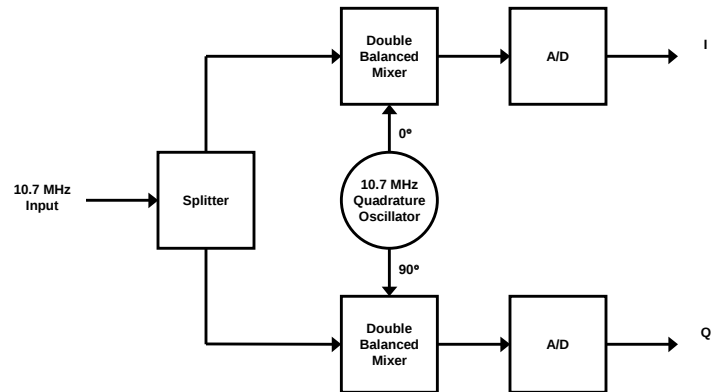


- 10.7 MHz center frequency
- CW1 = +1 kHz
- CW2 = -19 kHz
- FM = +12 kHz
- BPSK = -18 kHz
- Transponder = -16 kHz to 0 Hz

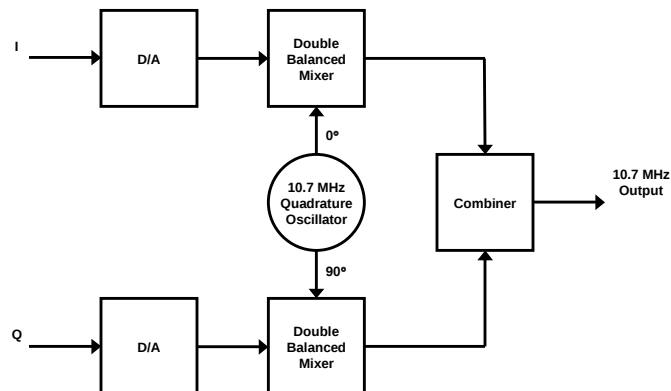
SDX Hardware Architecture



I/Q Demodulator



I/Q Modulator



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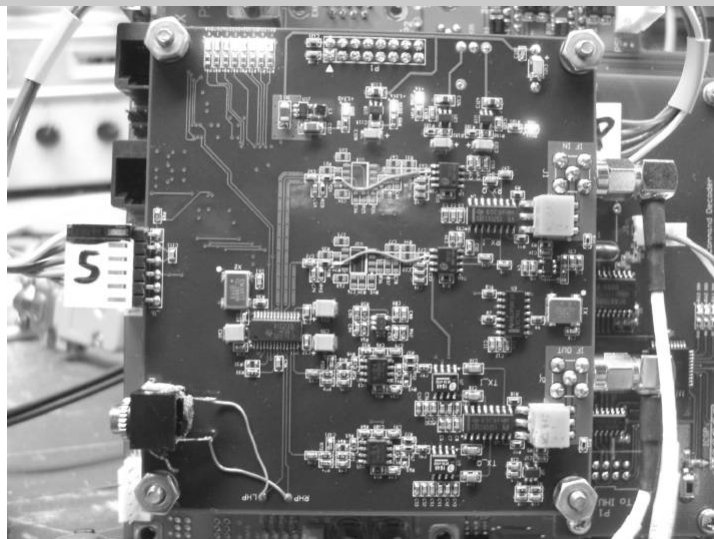
Digital Processor



- Microchip PIC32 (MIPS core)
- 512k Program memory
- 32k RAM
- 80 MHz clock
- No floating point processor

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SDX Card

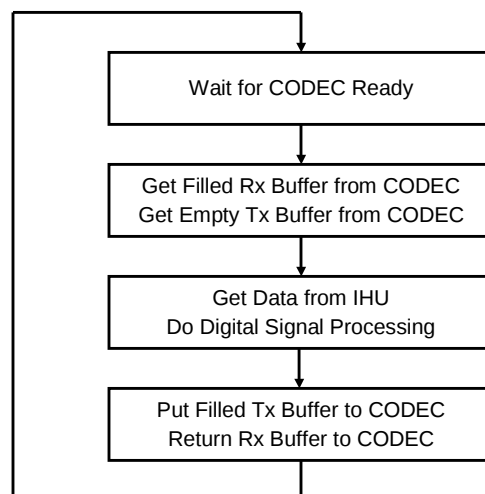


SDX Software

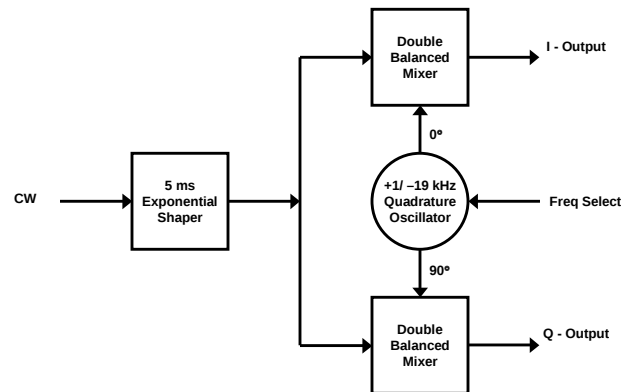


- Calculates 96,000 total (I&Q,) 16-bit samples every second
- Generates all RF outputs simultaneously
- No floating point math
- Must use CPU cycles carefully!

Software Architecture



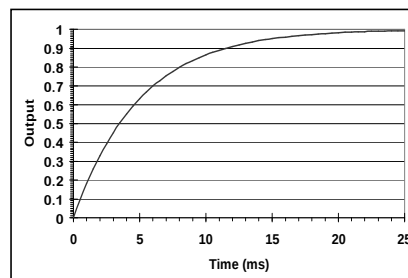
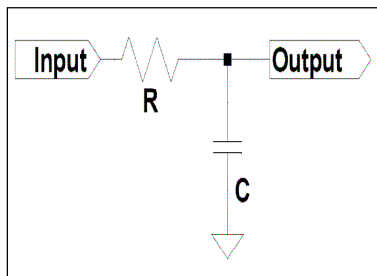
DSP - CW Beacon



5 ms Exponential Shaper



- Works like a simple RC circuit
- $\tau = RC = 5 \text{ ms}$



⋮

5 ms Exponential Shaper



$$Y_n = Y_{n-1} + (X_n - Y_{n-1}) \tau'$$

```
// Create nice CW Envelope as per ARRL  
Envelope += ((CWInput - Envelope) * CWTimeConstant) >> 15;
```

⋮

Quadrature Oscillator



- 2 outputs, 90 degrees out of phase
- Compute next carrier phase angle
- $\theta_n = \theta_{n-1} + \Delta$
- Take both Sine(θ_n) and Cosine(θ_n)

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Quadrature Oscillator



- $\theta_n = \theta_{n-1} + \Delta$
- Take both Sine(θ_n) and Cosine(θ_n)

```
// Get next CW Carrier Phase
CarrierPhase = (CarrierPhase + PhaseDelta) & TRIGANGLEMASK;

...Sin(CarrierPhase)...
...Cos(CarrierPhase)...
```

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CW Beacon Code



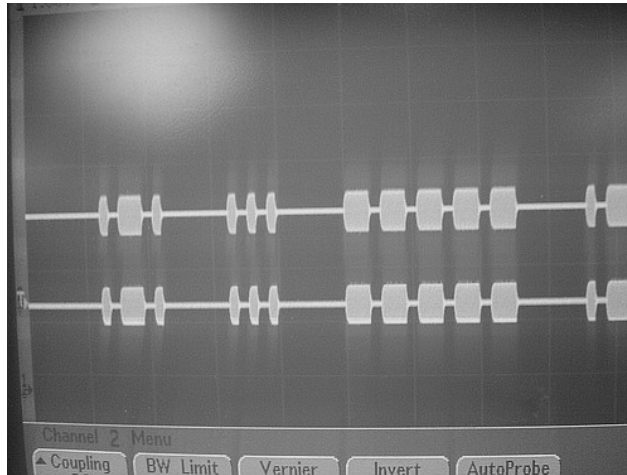
- Create 5 ms envelope
- Compute carrier phase: $\theta_n = \theta_{n-1} + \Delta$
- Take both Sine(θ_n) and Cosine(θ_n)
- Multiply by 5 ms envelope

```
// Create nice CW Envelope as per ARRL
Envelope += ((CWInput - Envelope) * CWTimeConstant) >> 15;

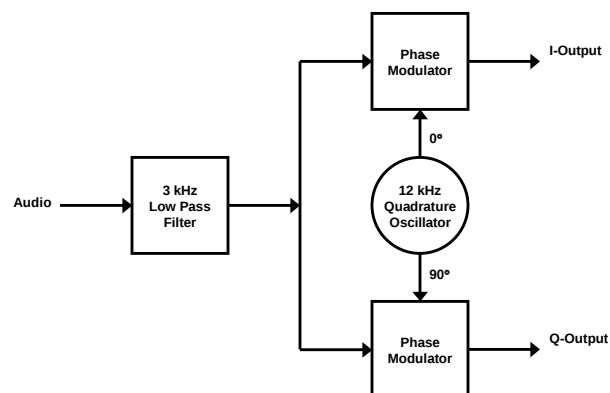
// Get next CW Carrier Phase
CarrierPhase = (CarrierPhase + PhaseDelta) & TRIGANGLEMASK;

// Modulate Carrier with Envelope to make Samples
ISample = ( Envelope * Sin(CarrierPhase) + Q15K ) >> 15;
QSample = ( Envelope * Cos(CarrierPhase) + Q15K ) >> 15;
```

CW Beacon Operating



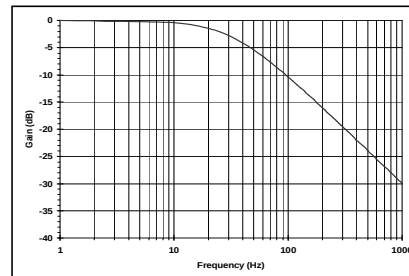
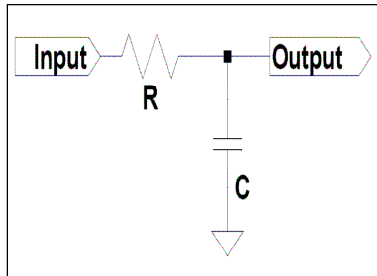
DSP - FM Audio



Basic Low Pass Filter



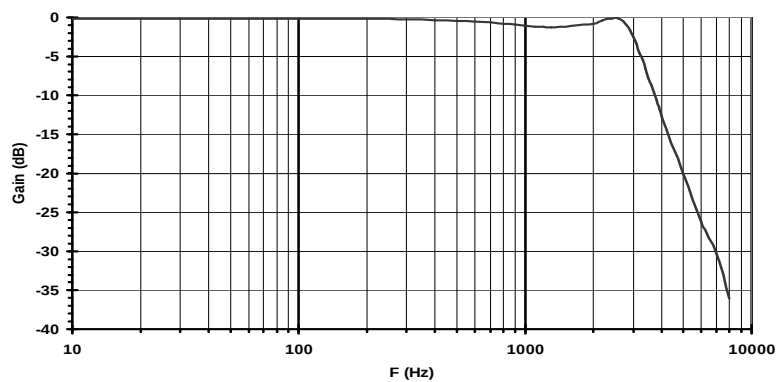
- $\tau = RC = 5 \text{ ms}$
- $f_c = 1/2\pi\tau \sim 32 \text{ Hz}$
- $Y_n = X_n\tau' + Y_{n-1}(1-\tau')$



3kHz Low Pass Filter



$$Y_n = X_n A_3 + X_{n-1} A_2 + X_{n-2} A_1 + X_{n-3} A_0 + Y_{n-1} B_2 + Y_{n-2} B_1 + Y_{n-3} B_0$$



Phase Modulator

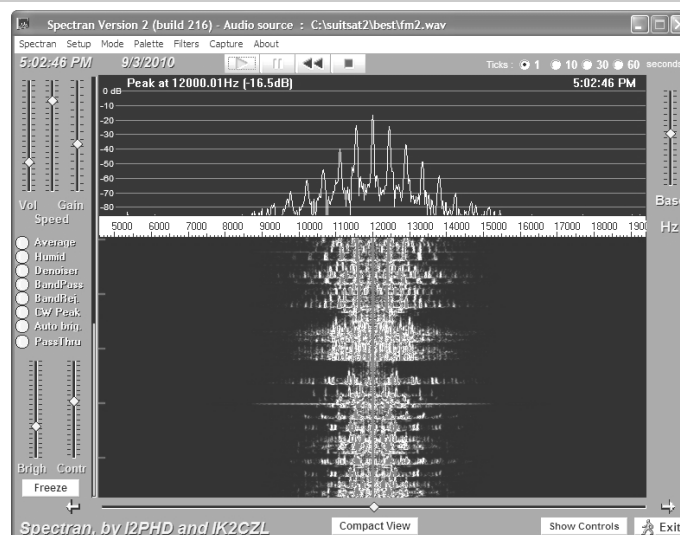


- Compute carrier phase angle
- $\theta_n = \theta_{n-1} + \Delta$
- Calculate modulation angle ϕ
- Take $\text{Sine}(\theta_n + \phi)$ and $\text{Cosine}(\theta_n + \phi)$

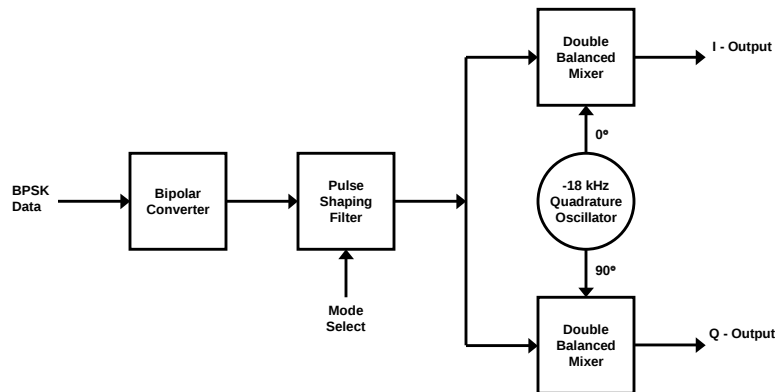
```
//***** Get next FM Carrier Phase *****
CarrierPhase = (CarrierPhase + FMPhaseDelta) & TRIGANGLEMASK;

//***** Create FM Samples *****
ISample = Sin(CarrierPhase + Phi);
QSample = Cos(CarrierPhase + Phi);
```

FM Audio Operating



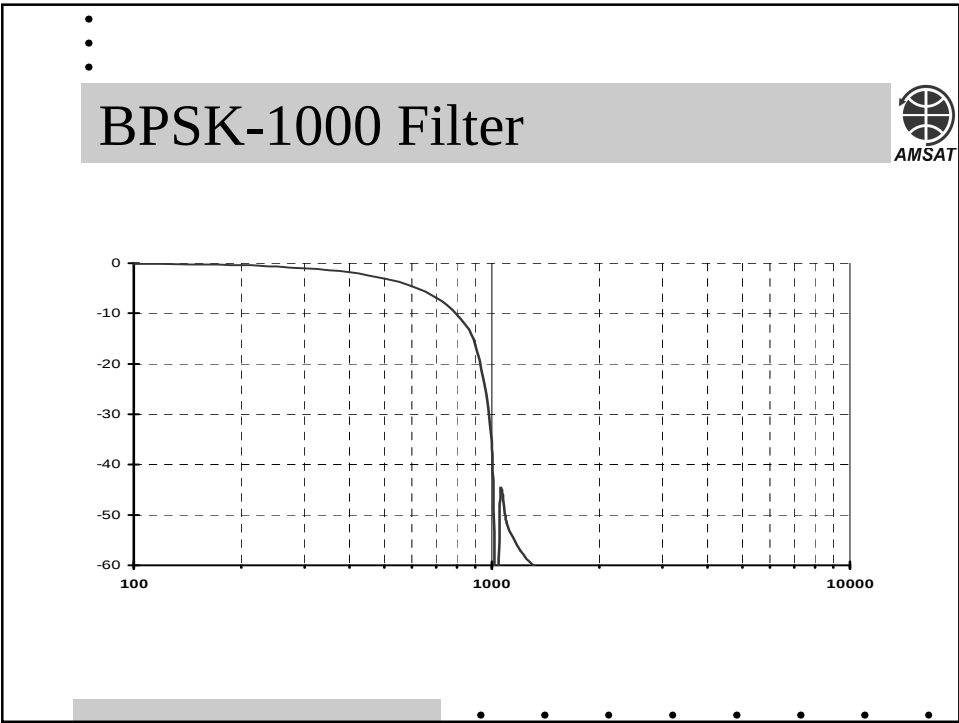
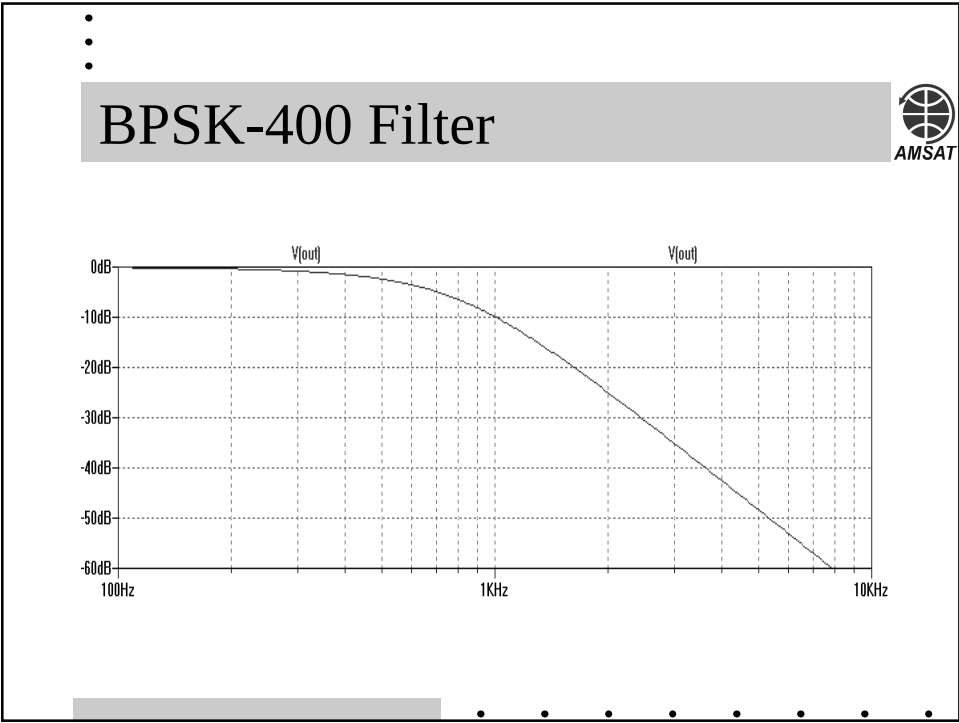
DSP - BPSK

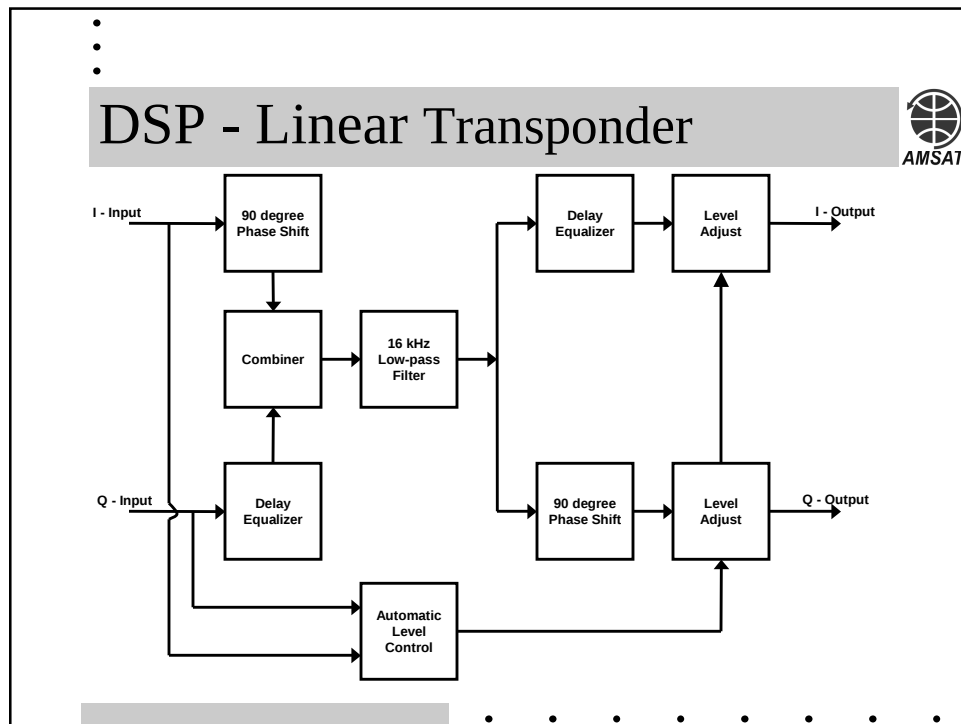


BPSK Modes



- BPSK-400
 - Like P3 satellites
 - Backup
- BPSK-1000
 - New mode w/FEC from Phil, KA9Q
 - Less bandwidth
 - Higher bit rate





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SDX Status

- Development complete
- Hardware and software are open source
- SDX integrated and tested with RF transceiver module
- Transponder used to make QSOs

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Acknowledgements

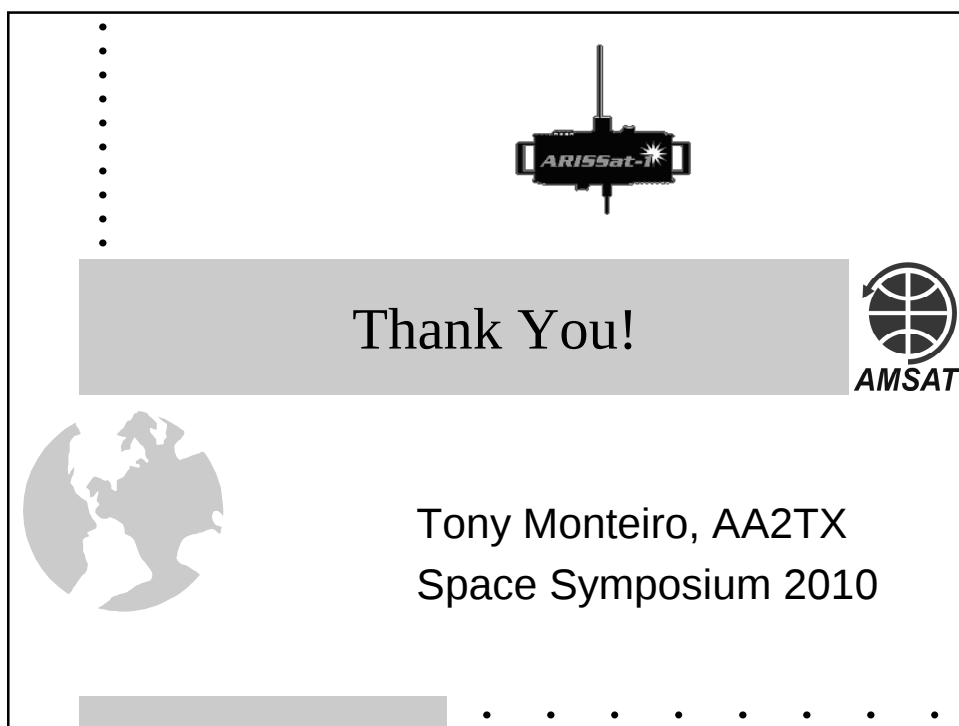


- Bob McGwier, N4HY
- Steve Bible, N7HPR
- Tim Moffat
- Joe Julicher, N9WXU
- Jerry Zdenek, N9YTK
- Jim Johns, KA0IQT
- Bill Reed, NX5R
- Phil Karn, KA9Q

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Any Questions?





The BPSK1000 Telemetry Modem for ARISSat-1

Phil Karn, KA9Q

Introduction

The ARISSat-1 (formerly Suitsat-2) spacecraft is planned for launch on a Russian *Progress* supply flight to the International Space Station (ISS) sometime in 2011 where it will be deployed as a free flying satellite.

ARISSat-1 will carry a new telemetry modulation and coding scheme, BPSK1000, designed to handle the severe fading often encountered with low orbit satellites without attitude control. Its performance and the link budgets for the ARISSat-1 spacecraft are such that reliable reception should require only a simple whip or ground plane antenna, a conventional 2m SSB receiver, and a reasonably modern personal computer with audio A/D input.

BPSK1000 uses differential binary phase shift keying (DBPSK) at a channel symbol rate of 1 kHz in a SSB bandwidth. With constraint length 7, rate $\frac{1}{2}$ forward error correction (FEC), the user data rate is about 500 bits/sec. HDLC framing provides application flexibility (including the ability to carry AX.25 in other applications) and a deep (16 second) convolutional interleaver provides strong protection against fading.

I hope that the demonstrated performance of BPSK1000 on ARISSat-1 will encourage other amateur satellite projects with similar needs to consider it; at the very least, I hope to convince other satellite designers that forward error correction (FEC) should be a standard feature of *every* amateur satellite data link!

Software to demodulate and decode the ARISSat-1 BPSK1000 beacon will be available for Microsoft Windows, Mac OSX and Linux. I wrote the reference BPSK1000 demodulator and decoder in C under Mac OSX and Linux as libraries and command line tools and I am distributing them under the terms of the GNU General Public License (GPL). I strongly encourage everyone to study, modify, enhance, test, break, fix, improve, experiment with and use what I have written.

My reference decoder is incorporated into the Windows program by Doug Quagliana KA2UPW and the Mac OSX program by Gilbert Mackall N3RZN, both of whom have turned a set of command line tools into complete, user-friendly applications.

My software can use, but does not require, multiple CPUs and the AltiVec (Power PC) or SSE (Intel/AMD) vector instruction sets to improve performance, in some cases rather dramatically. Multiple CPUs are used through the POSIX Threads (pthreads) library, and vector instructions are invoked with gcc C compiler intrinsics; there is no actual assembly code.

The rest of this paper discusses the physical layer modulation, interleaving, coding, and framing elements of the generic BPSK1000 air interface. Its specific use by ARISSat-1 is documented separately.

Requirements

Engineering is all about making tradeoffs, and the design of a digital modem is no exception. Every engineering project should start with a clear list of requirements. For a modem, making and meeting those requirements requires a good understanding of the channel on which it is to operate.

Since classroom educational demonstrations are a prime goal of ARISSat-1, my goal was to design a signal format that, while as robust and efficient as possible, should not require any special hardware beyond a general purpose personal computer and a 2-meter receiver or transceiver. Nor should it require any special knowledge, training or practice beyond ordinary ham radio skills. I especially did not want to assume that the operator was already an experienced amateur satellite operator. I want to make it possible for *any* ham with the necessary equipment, not necessarily one already familiar with amateur satellites, to do a successful classroom demonstration. My hope is that this may entice more kids to become hams, and more hams to join AMSAT.

No one gave me a formal list of requirements beyond "it must work" and "we must have it before such and such date", so I made my own:

Requirement #1: No special RF equipment needed.

It must be possible to receive the ARISSat-1 telemetry with a stock 2m SSB amateur radio transceiver. As nice as it would be to use a software defined radio capable of wideband operation, that would be more appropriate for a future mission, not one intended primarily for school demonstrations and general education.

Requirement #2: Good power efficiency.

DC power is at an absolute premium on any spacecraft, and downlink transmitters invariably take the lion's share of that power. The downlink mode must be as power-efficient as possible.

Additionally, it should be possible to reliably receive ARISSat-1 telemetry with a small and simple antenna such as an ordinary whip or ground plane. Steered directional antennas should not be required.

Although it would be nice to work with FM-only transceivers, FM is just too inefficient for satellite use. Implementing an efficient modulation mode in software requires a linear transceiver, and that currently means SSB. This leads to the requirement that the signal fit within the typical SSB voice filter response of 300 to 2700 Hz, a bandwidth of 2400 Hz.

A prime personal goal of this project -- as with my previous effort that put an experimental FEC format on AO-40 -- is to demonstrate that there exist far more power-efficient modulation and coding methods for amateur satellite telemetry links than are generally flown. Such improvements can either cut the cost of constructing a satellite by reducing the amount of DC power it must generate, and/or it can make amateur satellites accessible to more hams by

reducing the size, cost and complexity of the ground antennas. Many hams live in homes with antenna restrictions where the traditional 2m/70cm yagi combination simply isn't an option.

The AFSK/FM mode used by terrestrial amateur packet radio is *particularly* inefficient. Quite frankly I am at a loss to understand why anyone would fly it on a spacecraft.

Because forward error correction (FEC) codes can provide a significant "coding gain" that reduces the transmitted energy per bit, this requirement alone dictates the use of FEC, even without the additional dramatic improvements it provides in fading (see below). It has long been easy to achieve coding gains of up to 7 dB on channels impaired by only gaussian (thermal) noise, and the latest codes can provide gains of up to about 10 dB.

Requirement #3: Fade tolerance

Closely related to the previous requirement is the need to tolerate the unpredictable and often-deep fades often encountered with amateur satellites in low earth orbit. Although the line of sight from satellite to ground station may not be interrupted, amateur spacecraft (such as ARISSat-1) are typically uncontrolled or partly controlled in attitude (e.g., with bar magnets), with the result that antenna nulls can sweep across the ground station and produce deep nulls. Multipath fading can also occur when omnidirectional ground antennas pick up reflections of the satellite signal from the ground or nearby buildings.

This requirement is closely related to #2 because an inefficient link (i.e., one without FEC) requires a lot of excess power to ride through a fade. An alternative is to keep retransmitting until the data gets through, but all those unsuccessful transmissions are also wasted energy. Fading represents errors that can be corrected by FEC, but not all FEC codes can tolerate the long bursts of errors associated with slow fading. Therefore, we need either FEC suited for burst error correction or an interleaver to break up error bursts into a long series of single bit errors that can be corrected more easily.

To see the huge benefit of FEC on fading channels, consider that without coding you need enough link margin -- excess transmitter power -- to ride through the usual fades. I.e., it must be designed for the worst case. Since the channel is faded for only a small fraction of the time, most of the time all that excess power goes to waste. On the other hand, a well designed FEC scheme for a fading channel will operate as long as the *average* signal-to-noise ratio is high enough; brief fades, even when infinitely deep, can be reconstructed by the decoder from redundant information received when the channel is not faded. This difference between average and worst case SNR becomes the effective coding gain of the FEC. When the fades become very deep, the coding gains can become truly dramatic. The link simply won't work without it.

Requirement #4: The average amateur should be able to tune the signal by ear without specialized skill or an excessive amount of practice.

Doppler shift from a LEO satellite on 2 meters is about +/- 3.3 kHz so tuning of a SSB receiver is obviously required throughout the pass. As desirable as computer controlled tuning may be, I did not want to require it.

I probably spent more time thinking about how best to meet this requirement than all the others combined. The problem is that efficient digital modes tend to sound like bandlimited white noise, and white noise is notoriously hard to tune to an exact frequency! [\[1\]](#)

Fortunately, an elegant and effective solution presented itself. The ARISSat-1 downlink also includes a CW beacon and I recommended that it simply be moved to the lower null of the digital telemetry signal. Here it will not interfere with the beacon and vice versa, but it can easily be heard and tuned by a human operator in such a way that it automatically tunes the telemetry signal as well.

Requirement #5: the transmitter must be simple.

Although ARISSat-1 carries a lot of processing power by satellite standards, CPU cycles and memory are both still quite limited in comparison to a typical personal computer. The IHU and DSP have many other things to do besides encode telemetry. Even when there's plenty of real time, you still want to minimize the number of executed instructions because every one of them requires some amount of energy to execute.

The only element of signal generation that created any concerns was the BPSK modulation. Not the modulation per se, but the filtering associated with it. The FIR filter is 454 taps long, but not every tap needs to be computed on every sample. By signalling with impulses, most of the delay line will contain zeros, allowing those multiplications to be skipped.

Fortunately, generating BPSK1000 is relatively simple -- certainly far simpler than demodulating and decoding it!

Signal Design

My job here is to carry packets or frames of arbitrary data from the ARISSat-1 experiments and onboard computer (IHU) to a ground station where they can be decoded and displayed by a computer running special software. This paper does not define or describe the actual data to be carried on this link, so my description here starts with the framing layer and works down to the modulation used on the physical channel. Consult the other papers on ARISSat-1 for information on the contents of the frames actually transmitted during flight.

BPSK1000 encoding can be succinctly described as follows:

- HDLC framing with a 32-bit CRC;
- constraint length 7, rate $\frac{1}{2}$ convolutional forward error correction (FEC) coding;
- 128-way convolutional interleaving with "bit reversed" delay line ordering; and
- DBPSK (Differential Binary Phase Shift Keying) modulation.

These elements are all "off the shelf", well documented in the textbooks and used commercially for many years. What follows is a more detailed description and my rationale for selecting each one for this project.

Framing

When I started work on this format, the telemetry data formats and sizes were not yet established. Rather than pick a frame size that would almost certainly turn out to be wrong, I chose to support variable length framing for its versatility.

One of the best known and most widely used methods of variable length framing on synchronous bitstreams is HDLC, familiar to most hams from its use in the AX.25 packet radio protocol. Stripped to its bare essentials, this is what an HDLC frame in BPSK1000 looks like:

01111110	Data (variable)	CRC-32	01111110
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The special 'flag' sequence 01111110 represents the end of one frame and the start of another. (Two frames may share a common flag, or there may be extra flags between frames; the decoder will work either way.) As called for in the HDLC standard, user data is transmitted least-significant-bit first between the opening flag and the CRC.

To ensure transparency, the HDLC encoder inserts a '0' bit whenever five contiguous '1' bits occur in the data stream. When the receiver sees five '1' bits followed by a '0', it automatically removes the '0'. Although bit stuffing can consume up to 16.7% of the channel capacity in overhead, this occurs only for a data stream of all 1's. The overhead for bit stuffing on random data is much less.

I made only one significant change to standard HDLC framing as used in BPSK1000: I replaced the usual 16-bit CRC with a 32-bit CRC with the generator polynomial: [\[2\]](#)

$$x^{32} + x^{26} + x^{23} + x^{22} + x^{16} + x^{12} + x^{11} + x^{10} + x^8 + x^7 + x^5 + x^4 + x^2 + x + 1.$$

The stronger CRC greatly reduces the chance that a random bit stream will decode as a valid frame.

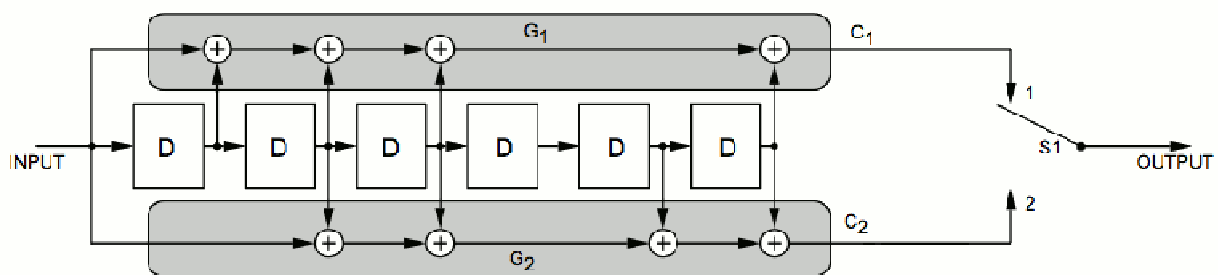
BPSK1000 treats the contents of the "Data" field as opaque, i.e., it does not care about their contents. Although ARISSat-1 doesn't send AX.25 headers, nothing prevents another BPSK1000 application from doing so. I.e., BPSK1000 could easily carry standard AX.25 packet radio data, although for reasons discussed later it is not well suited to the half duplex, shared channel mode of operation of most amateur packet radio channels.

The fact that BPSK1000 does not assume the presence of AX.25 headers is one reason I decided to enlarge the CRC. Spurious HDLC frames are common in packet radio but they are easy to detect by their absence of an AX.25 header. Because I did not want to make any assumptions about the contents of ARISSat-1 HDLC frames, I chose a longer CRC that all but eliminates spurious frames in the first place.

In sum, HDLC converts an asynchronous stream of arbitrary length frames into a continuous 500 bps bit stream for the FEC encoder. If there's nothing to send, the HDLC encoder must HDLC flags. The HDLC decoder at the receiver regenerates the original series of frames with the 32-bit CRC providing strong error detection. Although BPSK1000 includes forward error correction (FEC), the HDLC CRC is necessary because a Viterbi decoder still makes errors when its error correction ability is exceeded and it cannot reliably signal when they occur.

Convolutional Error Correction Coding

To allow for the correction of a limited number of channel errors, the HDLC-encoded bit stream is convolutionally encoded with the CCSDS standard constraint length 7, rate $\frac{1}{2}$ convolutional code using connection vectors $G_1=1111001$ binary (171 octal) and $G_2=1011011$ binary (133 octal): [\[3\]](#)



For each data bit from the HDLC encoder, the convolutional encoder generates two symbols, C1 and then C2. I use the CCSDS convention for the ordering of the two encoded symbols but I do not invert either symbol.

The CCSDS and JPL versions of this encoder both invert the output of the 133 (octal) XOR ladder (shown here as symbol C2). Their reason for doing so is to limit the maximum possible number of contiguous 0's or 1's that can come out of the encoder regardless of the data so as to guarantee a minimum symbol transition density for demodulator tracking. That is unnecessary here because HDLC bit-stuffing ensures that no more than five consecutive '1' bits can ever occur in user data, and an HDLC flag consists of six consecutive '1' bits. An HDLC abort, if ever generated, need (and should) consist of only seven '1' bits, followed by an idle flag stream until more data is available for transmission. [\[4\]](#)

Although HDLC does not limit runs of '0' bits, this is not necessary here because of the use of differential encoding before BPSK modulation that turns every '0' bit into a 180° carrier phase transition. It is only necessary to break up consecutive '1' bits as differential encoding sends them as no change in carrier phase.

Convolutional Interleaving

Viterbi decoders tolerate burst errors poorly. Since a major requirement for ARISSat-1 is to mitigate the deep fading common with unstabilized satellites in low earth orbit, an interleaver is necessary.

Interleaving scatters the encoded symbols in time before transmission and rearranges them into their original sequence at the receiver before decoding. This has the effect of breaking up a burst of errors into a much longer sequence of single bit errors that are much more easily corrected.

There are two major classes of interleavers: block and convolutional. Block interleaving is straightforward: the encoded symbols are written into an array by rows and read out by columns for transmission. The receiver reverses the process by writing the array by columns and reading it out by rows.

Delay can be a problem with block interleaving, especially when a large block is required to tolerate deep fades. Nearly the entire block has to be written before transmission can start, and then the entire block has to be received before decoding can even begin. Block interleaving usually requires that a single block size be selected in advance, though some systems use several sizes. However, this doesn't necessarily restrict the system to a fixed data frame size; HDLC or something similar could support variable length data frames just as it does here.

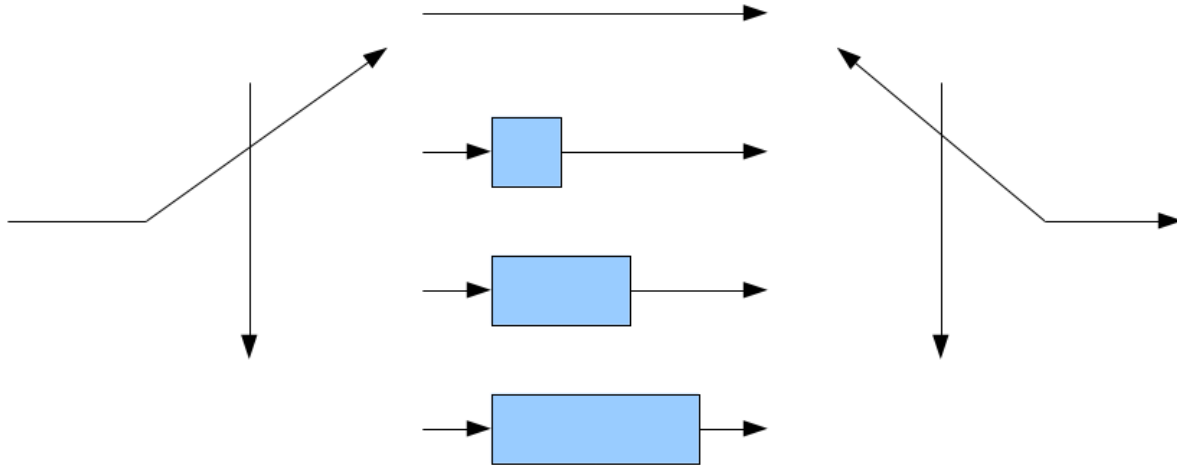
These drawbacks are not necessarily serious. For example, in its FEC mode the AO-40 IHU generated fixed sized 256-byte data blocks more or less instantly, so the delay from block generation in software to the decoded block being available on the ground was equal to just one block transmission time (13 sec) plus the times needed for the IHU to encode it and the ground CPU to decode it.

But when the source is a steady bit stream, or a series of small data frames spread out in time, the encoder must wait for the interleaver block to fill before it can even begin to transmit it. The last data frame in the block will not see any difference, but this can nearly double the time between the generation of the first (small) data frame in the block and when it is available on the ground.

[\[6\]](#)

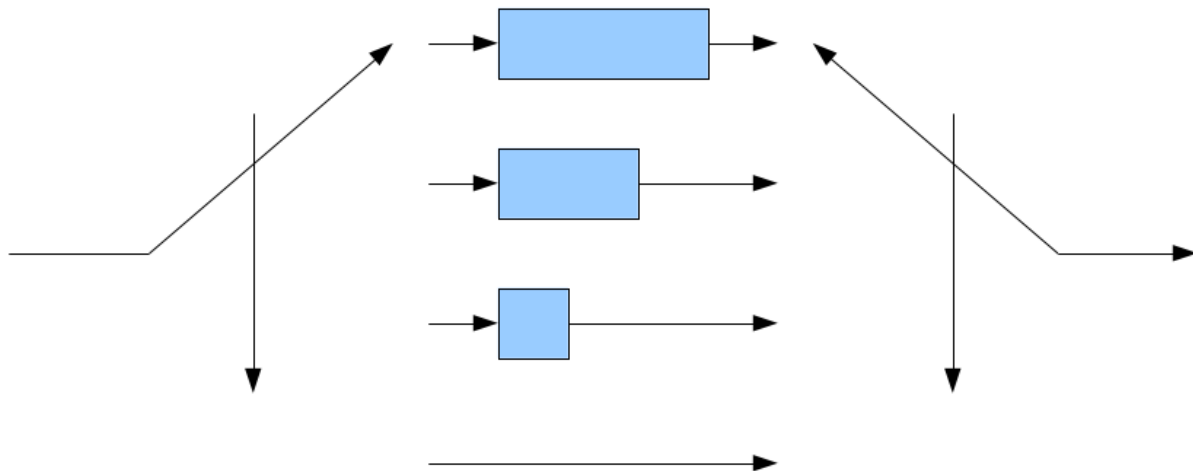
An alternative to block interleaving is convolutional interleaving, [\[5\]](#) and I chose it for BPSK1000 to help reduce latency when small HDLC frames are carried. Just as a convolutional encoder differs from a block encoder by operating on a continuous data stream rather than fixed-sized blocks, a convolutional interleaver also operates on a continuous stream. This is well suited to the continuous stream of encoded symbols from the convolutional encoder.

Here is a block diagram of a small (order 4) convolutional interleaver:



The symbol stream to be transmitted is fed in on the left to the 1:4 rotary switch that deposits each symbol in turn into one of four delay lines whose lengths range from 0 in the first row (no delay) to 3 time units in the last row. Their outputs are collected by the 4:1 rotary switch operating synchronously with the input switch. The delay lines clock only when selected by the rotary switches, which operate synchronously, and the output of the right hand rotary switch goes to the transmitter.

At the receiver, the incoming symbol stream passes through the deinterleaver, the mirror image of the interleaver:



The essential feature of convolutional interleaving is that in each row, the length of the interleaver delay line plus the length of the deinterleaver delay line is a constant, N . In this example, $N = 3$. So the overall effect of the interleaver and deinterleaver combined is to reproduce the original input stream, in its original sequence, delayed by a number of time units equal to N times the number of rows R ; in this example, that would be 12 time units.

N can actually be any number you choose, though it can't be less than $R-1$ if each row is to have a delay on each side of the channel different from all the other rows. Otherwise some input symbols will be sent in their original order, and that defeats the point of interleaving. And if you make N bigger than this, you're just adding unnecessary delay. So for all practical purposes, $N = R-1$.

The main advantage of convolutional interleaving over block interleaving is that less memory and less end-to-end delay are required for a given amount of fade protection. One can think of convolutional interleaving as being something like block interleaving but with a single block split between transmitter and receiver.

Convolutional interleaving also has its drawbacks. Because there's no well defined start or finish to the data stream as in block interleaving, it is not well suited to short bursty transmissions like those on a shared, multiple access channel (e.g., conventional packet radio). Conversely, a system that uses block interleaving could key up, send a single block and stop transmitting without having to allow any time to "prime" the de-interleaver or to flush the interleaver.

But that doesn't matter for our application because it's a one-way continuous broadcast. The ground station will still need to prime its de-interleaver at the beginning of the pass. At first this might seem a disadvantage relative to block interleaving, but it's not. Satellite AOS can occur at

any time, and were it to occur in the middle of a block in a block-interleaved system you'd have to wait up to one block time for the first full block to start. With convolutional interleaving, priming of the de-interleaver takes the same amount of time no matter when you start.

Bit-reversal convolutional interleaving

In most convolutional interleavers, the delay in each row is monotonically increasing (and decreasing at the deinterleaver, or vice versa). But this isn't mandatory. Just as the rows and columns of a block interleaver can be written in any order (even random) so long as the receiver mirrors the transmitter and puts everything back in its original place, anything goes.

This got me thinking about playing with some alternative orderings. One common trick in block interleaving is to access the rows and columns in "bit reversed" order. Take the integers from 0-7 and write them in binary:

000, 001, 010, 011, 100, 101, 110, 111

Now reverse them left-right and convert back to decimal:

0, 4, 2, 6, 1, 5, 3, 7

Now access the rows or columns in that permuted order.

Why do this? Well, it helps to spread out adjacent input symbols during an error burst (e.g., a fade). The first errored symbols in the burst are as far apart as they can get in the memory available. Additional errors are evenly sprinkled between the previous errors, though of course if the burst lasts long enough it will eventually have to fill in all the gaps and decoding failures will occur.

Bit reversal interleaving requires that the number of rows be a power of two, so I chose an interleaving order of 128. This implies that each row contains a total delay of 128 bit times divided between transmitter and receiver for an end-to-end interleaving/deinterleaving delay of 16,384 symbols. [\[7\]](#)

Modulation

BPSK? QPSK?

The power efficiency requirement pretty much mandates either BPSK or QPSK. In theory, QPSK (quadrature phase shift keying) requires the same power as BPSK and only half the bandwidth. In practice it is difficult to make QPSK perform as well as BPSK especially when the data rate is low compared to the frequency uncertainty, as is the case here, because QPSK has much tighter receiver requirements than BPSK for carrier frequency and phase tracking. So despite the bandwidth limitations of SSB filters I decided to stick with BPSK. It has a very long history on amateur radio satellites and satellites in general. [\[8\]](#)

The requirement that the signal fit a SSB receiver means that the modulated bandwidth cannot exceed a typical SSB voice filter, usually about 2400 Hz. It should be somewhat narrower to allow for errors in tuning and to stay away from the nonlinear group delay distortion typically found at the edges of crystal filters designed for voice operation where such delay isn't a serious problem.

Signalling rate

The Nyquist bandwidth of BPSK is 1 bit/sec/Hz. That is, I could *in principle* fit 2,000 bits/sec into 2 kHz of a SSB passband while leaving 200 Hz on either side. But achieving 1 bit/sec/Hz with BPSK requires very tight filtering with very little tolerance of symbol timing errors and group delay distortion. The FIR filter used at both transmitter and receiver must be quite long to achieve the necessary response, and processing time in the onboard DSP is limited.

Tightly filtered BPSK also generates a fair bit of overshoot in the RF envelope. This rules out efficient constant-envelope amplification, although that's not a problem in ARISSat-1 because it already gives us a linear amplifier for the entire 2 meter downlink including the telemetry beacon.

So to be conservative, I selected a BPSK symbol rate of only 1 KHz (i.e., 1000 symbols/sec) with a raised-cosine filter having 100% excess bandwidth, i.e., 1/2 bits/sec/Hz. This is achieved with a finite-impulse-response (FIR) filter with 454 taps running at a sample rate of 48 kHz; the same filter taps are used as the matched filter in the demodulator on the ground. Although the resulting bandwidth is still 2 kHz, instead of being flat the signal spectrum rolls off from a peak at the nominal center frequency to nulls at ± 1 kHz, with relatively little energy near the nulls.

Manual tuning with the CW beacon

As mentioned in the requirements section, the CW beacon is placed in the lower null of the telemetry beacon spectrum, 1 kHz below the nominal carrier frequency of the BPSK signal. All the operator need do is tune the receiver in USB mode so that the CW beacon comes out at 500 Hz, and this will automatically center the BPSK signal in a typical SSB receiver bandwidth. I.e., the signal will extend from the lower null at 500 Hz to an upper null at 2500 Hz with the carrier at 1500 Hz, the nominal center of the SSB passband.

Why not coherent BPSK?

Because our spacecraft will transmit on 2 meters from low earth orbit, path losses will be relatively low and the signal will, on average, be fairly strong. But experience has shown that unstabilized spacecraft in low earth orbit often exhibit deep, unpredictable fading. That's the reason for the deep interleaver.

Fading (or its absence) is also a major consideration in the design of BPSK modems as it can be implemented in two very different ways depending on which channel impairment is more important: thermal (gaussian) noise or fading.

Satellite links are traditionally designed to minimize thermal noise, so most use a form of PSK that requires the receiver to form a clean local copy of the unmodulated signal carrier to serve as a phase reference for the receive signal. This is coherent demodulation.

This can be done in one of two ways. The first is for the transmitter to send a residual carrier along with the data so that the receiver can track it with a conventional phase lock loop (PLL). The second is for the receiver to reconstruct the carrier entirely from the data by stripping off the modulation.

Although residual carriers are still used in some deep space links, particularly at the extremely low data rates sent by a spacecraft in "safe mode", this takes power away from the data. It is much more common to suppress the carrier entirely at the transmitter so that all of the power can go into the data. The receiver recovers the carrier from the data with one of two mathematically equivalent methods: the squaring loop and the Costas loop.

Especially when strong FEC is used, these loops can suffer significantly from "squaring loss", an effect that reduces the signal-to-noise ratio of the recovered carrier. This happens because the raw symbols (before FEC decoding) are very weak, so when the loop strips off the modulation it does so with a fairly high error rate that degrades the recovered carrier.

Squaring loss can be overcome by merely narrowing the loop filter, effectively averaging out the noise over a longer interval that may span hundreds or even thousands of channel symbols. This is fine if the signal is very stable, as on most deep space links. But it can become completely unworkable when the signal is subject to rapid fading, e.g., on ionospheric or land mobile channels, especially at the low symbol rates we're using here.

We also have fading problems with our low earth orbiting spacecraft. Although we may have continuous line of sight, the spacecraft may tumble unpredictably and sweep antenna nulls past the receiver, causing deep fades accompanied by a sudden reversal of signal phase that would defeat a conventional coherent BPSK demodulator of the Costas or squaring loop type.

Differential BPSK

For this reason I have chosen a form of BPSK for ARISSat-1 that doesn't require the receiver to form a carrier phase reference. This is DBPSK, differential binary phase shift keying. It is generated just like ordinary BPSK with one crucial exception: before it modulates the transmitter, the data stream is differentially encoded so that a binary zero is transmitted as a 180° change in the phase of the transmitted carrier while a binary one is transmitted as no change from its previous state. This compares with conventional BPSK where a binary zero corresponds to the RF carrier with a 0 degree phase shift and a binary one corresponds to the RF carrier shifted by 180° .

The advantage of DBPSK for our application can be seen in how it is demodulated. The receiver can simply compare adjacent incoming symbols, looking for sudden 180° changes in phase - whatever it may be.

This is extremely easy to implement. In software (the only way to build modems nowadays!), the standard way to demodulate DBPSK is to first convert the input signal to complex baseband at zero frequency. That is, we generate a complex sinusoid (a matching sine and cosine wave) at the estimated signal frequency and multiply it by the input signal (which can be either complex or real) to produce a complex baseband signal at (approximately) zero frequency. If our frequency estimate is correct, an unmodulated carrier becomes a stationary phaser at some arbitrary phase angle (since we don't know or care about its phase). Should the signal flip phase by 180° , this phaser will rotate 180° . By computing the dot product of pairs of complex symbols we simultaneously demodulate the data and remove the differential encoding; this works because the dot product of a vector with itself is a positive number while the dot product of a vector with itself flipped 180° is a negative number.

So instead of generating a nice clean phase reference by averaging some hundreds of symbols, in DBPSK demodulation we just use each symbol as the phase reference for the next. The dot product yields a scalar (a number) that tells us how certain the symbol estimate is, just what we need for our soft-decision Viterbi decoder.

Effects of frequency errors on DBPSK demodulation

What is the effect of an error in the frequency estimate? If the local oscillator doesn't match the incoming signal frequency, then the baseband phaser will rotate clockwise or counterclockwise depending on whether the oscillator is above or below the actual signal frequency. But if the error is small, the vector will rotate very slowly. It may still rotate many times in a second, but because we're only comparing adjacent symbols -- not trying to form a reference from hundreds of them -- it only matters that it rotate no more than a few degrees during one symbol time.

Let's say the BPSK is at a symbol rate of 1 kHz and our frequency estimate is off by 100 Hz. The baseband phaser will rotate 100 times per second, but that's only 1/10 of a rotation (36°) from one symbol to the next. Because the magnitude of the dot product of two vectors is proportional to the cosine of the angle between them, a small frequency error decreases the magnitude of the dot product to $\cos(36^\circ) = 0.81$. This corresponds to a loss of $20 \cdot \log_{10}(0.81) = -1.84$ dB. If the frequency error can be kept to 50 Hz, then the loss is only $20 \cdot \log_{10}(\cos(18^\circ)) = -0.44$ dB, a tolerable figure.

Decoding BPSK1000

Nearly every digital format is easier to generate than it is to decode, and BPSK1000 is no exception. This is because the receiver has to first determine various signal parameters before it can demodulate and decode the signal, and this searching and tracking consumes most of the CPU time.

Input format

My BPSK1000 demodulator accepts a 16-bit linear PCM audio signal sampled at 48 kHz. The sample rate is a compile-time constant; although it can be changed, the structure of the code

requires it to be an integer multiple of the symbol rate (1 kHz) so if you have a signal at some other sample rate (e.g., 44.1 kHz) it's easier to simply convert it with a tool like *sox*.

Chunking

My demodulator operates on blocks of PCM samples called "chunks". The chunk size, currently 512 symbols (512 ms), is chosen to contain enough energy for the carrier frequency and symbol timing search while being short enough that these parameters remain essentially constant within the chunk.

Carrier frequency and symbol timing search

The first step in decoding BPSK1000 is to determine the carrier frequency and symbol timing. Because it's DBPSK, an estimated frequency will do; as shown above, ± 50 Hz will do, so I search in 100 Hz steps. I must also determine where each symbol starts and stops. So I run a series of trial demodulations with every possible combination of carrier frequency (in 100 Hz steps) and symbol time. Since the sample rate is 48 times the symbol rate, this means trying 48 different hypotheses for symbol timing.

No attempt to acquire data is made at this stage. Only the total demodulated energy is calculated, and the carrier frequency and symbol timing parameters that yield the largest demodulated energy are taken as the best estimates. This step is both CPU intensive and parallelizable, so it's a natural for a machine with multiple CPU cores. But in practice this search is actually pretty fast except on very old and slow machines thanks to a fast FIR filter that uses vector instructions.

Carrier frequency refinement

After the initial estimate, the carrier frequency estimate is refined by simple linear extrapolation. As explained above, when a frequency error is present the baseband signal vector slowly rotates. This rotation can be detected by summing the magnitudes of the vector cross products of adjacent pairs of baseband phasors. When those vector cross products are zero (except for noise) the frequency error is zero. This step is actually overkill since, as stated, 50 Hz frequency errors have little effect on demodulation. I do it mainly to give the user a more precise frequency reading.

Tracking and demodulation

Once the carrier frequency and symbol timing are determined, there's no need to repeat the full-blown search unless the signal is lost. Changes in frequency and timing between each chunk are tracked by simply running a trial demodulation (and looking at the demodulated energy) at values bracketing the current estimates.

Then the data can finally be demodulated.

Deinterleaving and decoding

Convolutional interleaving, as described above, assumes that the rotary switches in the interleaver and deinterleaver are synchronized. If not, the deinterleaver produces garbage.

There are no sync patterns in the BPSK1000 format to indicate interleaver phasing. Correct interleaver phase has to be found by brute force, and this automatically synchronizes the Viterbi decoder phase as well. Once the DBPSK demodulator has acquired and demodulated a symbol stream, the soft decision samples are scaled and fed to 128 virtual deinterleavers, Viterbi decoders and HDLC decoders, one for every possible interleaver phase. Eventually, one of them will produce a HDLC frame with good CRC. Now that we know the correct phasing, the other 127 virtual decoders can be shut down. They remain shut down as long as we continue to get valid HDLC frames. If too much time passes without a valid frame, then all 128 decoders are re-enabled until another frame is decoded.

This was my main motive for using a 32-bit CRC with HDLC; I was concerned that spurious frames would occur frequently with the 16-bit CRC and interfere with the determination of the correct deinterleaver phase.

This brute force approach isn't nearly as bad as it sounds; even when all 128 decoders are running, DBPSK demodulation still takes about half of the program's total CPU time. Demodulation and decoding run in separate threads, both for architectural convenience and to take advantage of extra CPU cores.

Concluding thoughts

After the launch of AMSAT-OSCAR-40, I designed and implemented an experimental FEC-coded telemetry format (<http://www.ka9q.net/ao40/>) designed to deal with the deep periodic fading characteristic of the S2 transmitting antenna at high squint angles.

This project was very successful, though it was eventually cut short by the complete failure of the spacecraft. I learned a great deal from that experience, and while the ARISSat project has a different set of design objectives and constraints, I was able to reuse many important design elements.

Yet ARISSat-1 will be a very different spacecraft than AO-40, if only because it will operate from LEO while AO-40 was in a high orbit. BPSK1000 is also rather different from my AO-40 FEC design, partly because the latter was constrained to work with the existing Phase III IHU hardware and software: the symbol rate had to be 400 Hz, the modulation had to be BPSK with Manchester (biphase) encoding, the data was fixed-length 256-byte blocks, and so on.

I had none of those constraints with ARISSat-1. In some ways that lack of constraints actually made BPSK1000 more difficult to design, but I think the result is better for it.

Although I've used mostly "off the shelf" modem design elements, as a system BPSK1000 is a new design that has never flown on an amateur radio satellite. I would have liked to implement a

range of operating modes, e.g., data rates, bandwidths and interleaver depths, selectable by command so that the optimal mode for the actual conditions could be selected in flight. This wasn't possible so I designed a single mode to be as robust as possible, eg., by picking a conservatively user low data rate. I very much look forward to seeing it operate from space so we can gain the experience necessary to design improved modems for future flights. With digital signal processing both on the ground and on the spacecraft, and with the new generation of software defined radios, the potential for new amateur satellite digital modes is extremely bright.

Footnotes

[1] Clarke's Law (after Arthur C. Clarke) states that any sufficiently advanced technology is indistinguishable from magic. My corollary to Clarke's Law states that any sufficiently advanced communication scheme is indistinguishable from white noise.

[2] For the 32-bit CRC polynomial I chose the one used in Ethernet, sometimes known as CRC-32.

[3] The polynomials and connection vectors for code generator polynomials can be written with either the most or least significant term first, often leading to considerable confusion. The convention here is taken from JPL Deep Space Network Handbook 810-005, 208A, page 12, in which the leftmost bit in the connection vector represents the taps encountered by the newest data bit entering the encoder. Some other references, plus my own software, use the opposite convention. This makes the vectors 1001111 and 1101101 binary; 117 and 155 octal, or 6D and 4F hex.

[4] The interleaver complicates this issue considerably. Even with HDLC bit stuffing (which I use) and alternate FEC symbol inversion (which I don't use) I can conceive of pathological cases where the interleaver might produce a very long string of 1's from a sequence with a bounded number of them. I could have added a scrambler, as I did for AO-40, but with the addition of HDLC bit stuffing I just didn't think the remaining problem was serious enough to warrant it here.

[5] Not to be confused with convolutional *coding*, which I'm also using here!

[6] As an analogy, consider a group of shuttle busses that run on demand. Each bus carries 50 people, and the drivers like to fill all the seats. If you're part of a group of 50 people who arrive at the bus stop together, you can quickly board the first bus and leave right away. But if 50 people arrive individually over the space of 15 minutes, the first person to board the bus will have to wait 15 minutes for the bus to fill before it leaves.

[7] Strictly speaking the delay should be $127 \times 128 = 16,256$ symbols but it the code was easier to write with a little more delay.

[8] Some amateur satellites using BPSK include the Phase 3 series (Phase 3A and Oscar 10, 13 and 40) and the Pacsat series, e.g., Oscar 16.

References

- HDLC framing is described in many places. Just a few include:
 - AX.25 Amateur Packet Radio Link Layer Protocol Version 2.2, 1998, <http://www.tapr.org/pdf/AX25.2.2.pdf>.
 - International Telecommunications Union X.25, Interface between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE) for terminals operating in the packet mode and connected to public data networks by dedicated circuit, <http://www.itu.int/rec/T-REC-X.25/en>
 - International Standard ISO/IEC 13239, "Telecommunications and information exchange between systems - High-level data link control (HDLC) procedures", http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=37010.
- The $k=7$ $r=1/2$ convolutional code is described in many places including:
 - DSN Telecommunications Link Design Handbook, 208, Rev. A Telemetry Data Decoding, May 18, 2009, <http://deepspace.jpl.nasa.gov/dsndocs/810-005/208/208A.pdf>
 - CCSDS 131.0-B-1, TM Synchronization and Channel Coding, Blue Book Issue 1, September 2003. <http://public.ccsds.org/publications/archive/131x0b1.pdf>
- [FEC Encoding for AO-40 Telemetry](#), including links to my published paper in the 2002 AMSAT Annual Meeting. (<http://www.ka9q.net/ao40/>)

ARISSatTLM - A Software Demodulator and Telemetry Display Program for the ARISSat-1 Satellite

Douglas D. Quagliana, KA2UPW/5
dquagliana@aol.com

Abstract

ARISSatTLM is a complete software DSP demodulator and telemetry display program for the telemetry from the ARISSat-1 satellite.

Introduction

ARISSatTLM is a graphical Windows program for displaying telemetry from the ARISSat-1 satellite (formerly known as SuitSat-2). The program is written in C, compiles with gcc, and is freely available under the terms of the GNU Public License (GPL).

ARISSatTLM includes C source code for the sound card routines originally written by Tony Monteiro, AA2TX, and a BPSK1000 software modem with digital signal processing source code originally written by Phil Karn, KA9Q. [1,2] Both were modified for use in ARISSatTLM. Karn's code was originally written for gcc on an Apple Mac computer, and required changes to compile under a similar version of the Cygwin gcc compiler for Windows. Similarly, Monteiro's code was written for a PC, but not written for gcc, and only minor changes were needed. ARISSatTLM provides some "glue," in the form of C code, to get the pieces to talk together. It also includes original code to display the decoded telemetry values. The software runs in real time on a 1 GHz Pentium III PC. It should be able to process prerecorded WAVE files on even slower machines.

ARISSatTLM configures the sound card to produce digital samples at 48000 samples per second with 16 bits per sample. This is the format that the BPSK1000 software modem expects. The bytes arrive from the sound card routines and are passed to the BPSK1000 software modem routines which extract the HDLC BPSK1000 frame. The BPSK1000 software modem routines then return the demodulated HDLC frames along with a length and a 32-bit CRC. These frames contain the telemetry values which ARISSatTLM then interprets and displays for the user.

Demodulated frames are also saved to a .CSV file on the local hard drive. The file will be named YYYY-MM-DD.CSV, where YYYY is the year, MM (or M) is the month, and DD (or D) is the date. Each frame is saved to the file by appending the file if the file already exists. This ensures that no received telemetry is accidentally overwritten. The frames are written to the file with one line per frame. Each frame starts with the date YYYY/MM/DD, a hyphen, the time (UTC) as HH:MM:SS, then each (raw) byte of the demodulated frame is written as a decimal value. For example, a telemetry frame line starts as

```
2010/06/26-14:55:48,084,107,014,000,000,072,105, ...
```

and an experiment frame starts as

2010/06/26-14:55:44,069,049,066,053,054,159,000, ...

The .CSV file can then be imported into any number of common spreadsheet programs for further analysis.

ARISSat-1 Frames

There are a couple different types of telemetry frames from ARISSat. The experiment frames contain data from the Kursk experiment, and the telemetry frames contain ARISSat telemetry.

ARISSAT-1 Experiment Frame

Description	Size	Notes
frame ID byte "E"	1 byte	hex 0x45, ASCII letter "E" for experiment
Experiment number	1 byte	This will always be "1" for the Kursk experiment.
Experiment Block ID	1 byte	hex 0x42, ASCII letter "B"
Experiment Block number	1 byte	While still on the satellite, the experiment data is broken into five pieces for transmission. This byte is the piece number (1-5) as an ASCII character 1,2,3,4 or 5 (hex 0x31 to hex 0x35).
Mission Elapsed Time	4 bytes	Mission Elapsed Time when the IHU received this 2k of experiment data from the Kursk experiment.
Experiment data	varies	Experiment data is broken up into five pieces for transmission. Four pieces will be 512 bytes. The fifth piece will be 36 bytes. ARISSat will join the pieces together into a Kursk experiment data frame[4] and will save it as a file called KURSK-nnnnn.EXP where nnnnn is the Mission Elapsed Time when the Kursk experiment frame was received.

The transmitted frames are expected to alternate between ARISSat telemetry frames and numbered experiment frames. The order should be T, E1B1, T, E1B2, T, E1B3, T, E1B4, T, E1B5. The Kursk experiment runs on a schedule and the experiment frames will most likely be the same five frames during any given satellite pass unless the experiment has just completed. The ARISSat telemetry frames will each be unique. There will probably be less than a second of delay between frames, during which only HDLC flags will be transmitted, but it will take several seconds to send a complete telemetry frame. [6]

The ARISSat telemetry frames consist of a frame ID, a counter, a traditional satellite "Hi" message, a collection of telemetry bytes based on a C language structure named `ss_telem_t`, and a CRC32. The actual definition of the `ss_telem_t` structure and all of the fields contained within it can be found at the bottom of the `ss_types_common.h` header file on the SVN in the "firmware common" directory. Interested readers may also want to consult the `ss_stdint.h` file in the same directory. The `ss_telem_t` structure within the ARISSat telemetry frame is a byte for byte copy of contents of a `ss_telem_t` struct in memory on the satellite.

ARISSAT-1 telemetry frame

Description	Size	Notes
frame ID byte "T"	1 byte	hex 0x54, ASCII letter "T" for telemetry
frame counter	4 bytes	4 byte integer counter
"Hi" message	22 bytes	The ASCII string "Hi, This is ARISSat-1."
ss_telem_t structure	290 bytes*	the ss_telem_t structure from the ss_types_common.h file
CRC32	4 bytes	CRC-32 as calculated by the spacecraft. Even though the demodulator software will verify the CRC to confirm a valid frame, we retain the CRC for end-to-end integrity checking. [5]

* The size of the ss_telem_t structure (and thus the total size of the "T" telemetry frames) has changed numerous times during the development of the satellite. It is possible that the size will change again before the satellite is launched. The information here should be considered to be preliminary. The ss_types_common.h file on the SVN will have the latest version of the ss_telem_t struct.

The ss_telem_t structure can be broken down into these major parts.

Overview of the ss_telem_t structure in the ARISSatTLM frame

Description	Size	Notes
Mission time	4 bytes	Mission Elapsed time (in seconds). This counter can reset back to zero.
Mission mode	4 bytes	One of "Emergency Power", "Lower Power", or "High Power"
IHU Temperatures	18 bytes	Temperatures measured from the IHU
Power	75 bytes	Current consumption and ON/OFF status for different parts of the satellite
PSU Status	21 bytes	PSU statistics
PPT Status	18 bytes	Solar panel current, voltage, temperature, etc. There are six copies in the frame (one for each solar panel and PPT).
IHU Status	52 bytes	IHU, PSU, SDX, Camera ON/OFF status
Calc	8 bytes	Telemetry values calculated from raw counts by the satellite (voltage, current, temperature)

Each of above telemetry sections can be broken down further into individual telemetry values. Unlike many other spacecraft which have single byte telemetry channels, ARISSat telemetry values vary in size from individual bit flags up through eight byte numeric values.

IHU Temperatures Telemetry

Description	Size	Notes
RF	2 bytes	RF module internal temperature
Control Panel	2 bytes	Control panel internal temperature
Experiment	2 bytes	Experiment temperature
Bottom Camera	2 bytes	Bottom Camera temperature
Top Camera	2 bytes	Top Camera temperature
IHU Enclosure	2 bytes	IHU Box temperature
Battery	2 bytes	Battery temperature
PSU PCB	2 bytes	PCB inside the IHU Box
IHU PCB	2 bytes	PCB inside the IHU Box

In order to convert the raw temperature values from these telemetry channels into degrees Celsius, the raw value should be scaled using the `scale_thermistor_C()` routine in the `scale_therm.c` file. This function will perform a lookup in a table that correctly converts the raw value to degrees Celsius.

Power Telemetry

Description	Size	Notes
Battery Status	12 bytes	2 bytes raw voltage; 2 bytes raw current; 2 bytes 2.5V reference; 6 bytes flight total net coulombs into battery
Battery History	12 bytes	6 bytes total charging into battery; 6 bytes total discharge out of battery
Camera Power	9 bytes	6 bytes total raw coulombs; 12 bits raw current value; four 2 bit status indicators for the four cameras
Experiment Power	8 bytes	6 bytes total coulombs; 12 bits raw current; 2 bits status
IHU	8 bytes	6 bytes total coulombs; 12 bits raw current; 2 bits status
SDX	8 bytes	6 bytes total coulombs; 12 bits raw current; 2 bits status
Power Supply 5V	8 bytes	6 bytes total coulombs; 12 bits raw current; 2 bits status
Power Supply 8V	8 bytes	6 bytes total coulombs; 12 bits raw current; 2 bits status
RF	1 byte	RF Power on/off
Spare	1 byte	Spare power on/off

The four two-bit camera status indicators will have a value of three for ON and zero for OFF. However, they will only have the value of three if the camera was actually turned ON taking a picture at the exact instant when the telemetry frame was being created by the spacecraft. Because the cameras are being turned ON and OFF, the status bits might appear as OFF in the telemetry frames even when pictures are being taken.

PSU Status Telemetry

Description	Size	Notes
Oscillator status	1 byte	Oscillator status
Crystal failed count	1 byte	Crystal failed count
Pin disturbs	1 byte	Flags if pin settings need to be changed
IHU forced reset count	1 byte	IHU forced reset count
SDX automatic turn on count	1 byte	SDX automatic turn on count
IHU recoveries count	1 byte	IHU recoveries count
Camera shutdown count	1 byte	Shutdowns due to low batteries
I2C wcol errors	1 byte	For I2C debugging
I2C overflow errors	1 byte	For I2C debugging
I2C bad message count	1 byte	Counts messages not formatted correctly
I2C bus idle resets count	1 byte	Counts resets due to lack of activity
I2C bus hang resets count	1 byte	Counts resets due to a stuck message
I2C bus reset sspcon	1 byte	SSPCON before bus is reset
I2C bus reset sspstat	1 byte	SSPSTAT before bus is reset
Command mismatch count	1 byte	Commands that were repeated to execute
PPT Poll Busy count	1 byte	Time to start the next poll and PPT is still being polled
PSU Reset reason	1 byte	The reset reason
PSU self-reset count	1 byte	Count of the number of times the PSU has reset itself

The PSU status telemetry is included for the ARISSat developers. These values are used for debugging purposes. ARISSatTLM does not currently display the PSU status telemetry.

PPT Status Telemetry

Description	Size	Notes
Panel Energy	6 bytes	Solar panel energy since last reboot
Panel Voltage	1 byte	Solar panel voltage
Panel Current	2 bytes	Contains 10 bit analog-to-digital converter output of the instantaneous current from this solar panel
Panel Temperature	12 bits	Solar panel temperature
Diode Temperature	12 bits	Diode temperature
Inductor Temperature	12 bits	Inductor temperature
FET Temperature	12 bits	FET temperature

Setpoint	1 byte	Solar panel current PWM setpoint
Age	1 byte	Indicates the age of the information from this PPT. A zero value indicates current information.
Corrupt count	1 byte	Count of corrupt packets from this PPT

There are six copies of the PPT Status telemetry in each ARISSat telemetry frame since there are six solar panels and six PPTs on the spacecraft. In each PPT status section there are two bytes that are logically split in half such that each four bit nibble contributes to a different telemetry value. This allows four twelve bit telemetry values to be transmitted in six bytes.

IHU Status Telemetry

Description	Size	Notes
Oscillator status	4 bytes	Oscillator status
Oscillator failed flag	1 byte	Flag if the IHU EC oscillator has failed
Core missed ticks counter	1 byte	Number of missed ticks in the core timer
Bad state flag	1 byte	Flag if illegal/unknown state is detected*
Bad NAK counter	1 byte	Unexpected NAKs*
Bus timeout counter	2 bytes	Bus timeouts*
Received too big	1 byte	Received too big
Receive errors	1 byte	Overflow / framing errors
UART receive errors	1 byte	Overflow / framing errors
Current state	1 byte	Current state
Bad state flag	1 byte	Illegal / unknown state detected
Full experiment runs count	1 byte	Number of times the experiment has been run fully
Quick experiment runs count	2 bytes	Number of times the experiment has been run just to collect data
Aborted power count	2 bytes	Number of times the experiment was running but was aborted due to power reasons
Quick timer	4 bytes	Timer for next experiment event
Full timer	4 bytes	Timer for next experiment full run
I2C timeout failed	1 byte	I2C timeout failed
Reset reason from RCON	4 bytes	Reset reason from RCON
Error PC	4 bytes	Error PC
PSU delayed response count	2 bytes	PSU request was still pending when the IHU went to process it
PSU error	2 bytes	PSU request contained an error when the IHU went to process it
PSU last error	1 byte	Last errored PSU request results

PSU stale seconds	2 bytes	How stale the PSU data is (in seconds)
ROM IDs sent counter	2 bytes	Number of ROM IDs sent
SD IDs sent counter	2 bytes	Number of SD IDs sent

* These values are repeated twice.

The IHU status telemetry is also included for the ARISSat developers. These values are used for debugging purposes. ARISSatTLM does not currently display the IHU status telemetry.

Calculated Telemetry

Description	Size	Notes
Battery voltage	2 bytes	Over the range -327.68 to 327.67 volts
Battery current	2 bytes	Over the range -4096 to 4096 mA (125uA/lb)
RF (8V) current	2 bytes	Over the range -4096 to 4096 mA (125uA/lb)
IHU Enclosure temperature	1 byte	IHU Enclosure temperature (-128 to 128 degrees C)
Control panel temperature	1 byte	Control panel temperature in degrees C

These values were calculated on-board the satellite and converted from raw counts to human readable formats.

Source Code Availability

For those who are interested in the ARISSatTLM source code, it is available on a software repository ("the SVN") along with over three gigabytes of other ARISSat-1 material. Under Windows, the SVN can be accessed using the (free) TortoiseSVN software[3], or directly via https. Interested readers can start at <https://svn.sarpeidon.net/viewvc>. The ARISSatTLM files are in the `ground_station_software/ARISSatTLM` directory. Currently the ARISSatTLM software can be compiled with gcc 4.2.4, in which case the executable requires the `demod.dll` and `cygwin1.dll` files, or with gcc 4.3.4, in which case the `demod.dll`, `cygwin1.dll`, and `cyggcc_s-1.dll` files are needed by the executable.

ARISSat Telemetry for Everyone

In addition to the Windows version of ARISSatTLM, there is also a version for Apple computers (ARISSat TLM) that is being developed independently by Gilbert Mackall. We are attempting to keep the telemetry display pages as similar as possible between architectures. Both programs use the exact same DSP routines for demodulating the audio signal into the HDLC frames and on-the-air performance is expected to be identical.

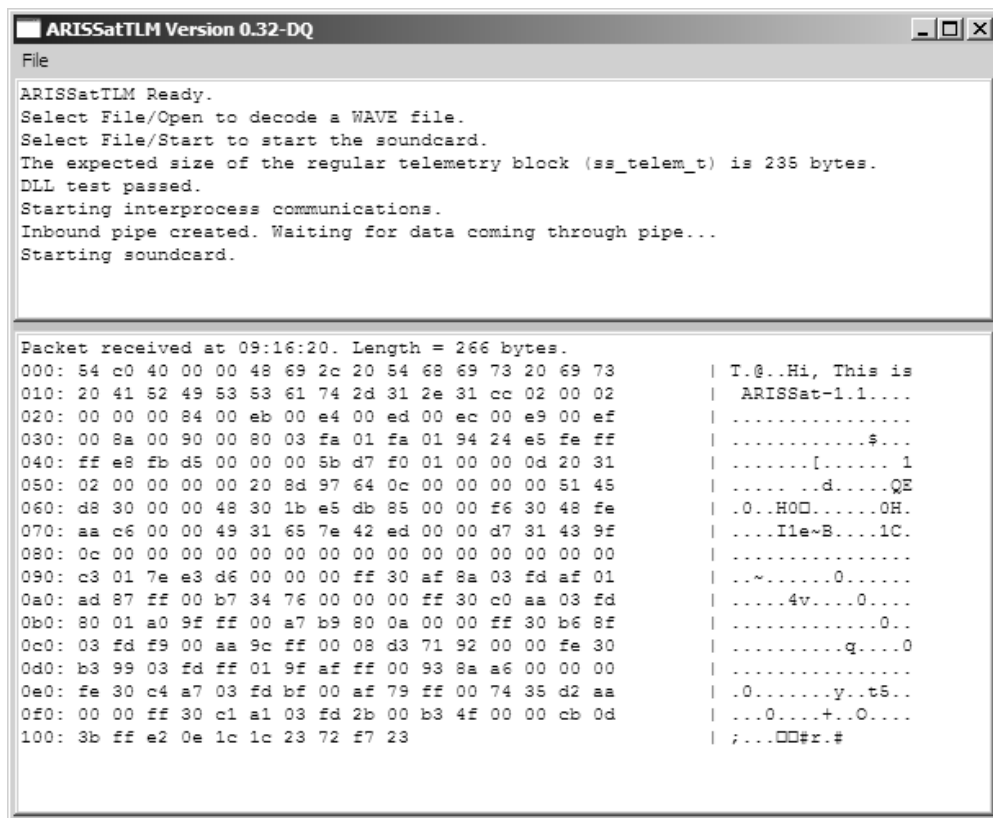
Those with mobile devices are not going to be left out either. We have plans for a web page on the www.arissattlm.org website which will contain (after ARISSat-1 is in orbit) a copy of the most recently received telemetry. There is a demonstration page at <http://www.arissattlm.org/mobile>. Currently this page is loaded with fictitious data, but it shows what the telemetry should look like when formatted for the smaller screens on mobile devices such as iPod touch and iPhone.

The Internet Telemetry Reflector

When the ARISSatTLM software is completed, demodulated frames will be sent to an Internet telemetry reflector. The reflector software will then combine all of the received telemetry frames, send telemetry frames in real time to anyone on the Internet who is interested using the Satellite Telemetry Protocol, update the www.arissattlm.org website with the latest telemetry, and update the telemetry archives.

Conclusion

Comments and criticisms on ARISSatTLM and the source code are welcome, as are bug reports and bug fixes.[7]

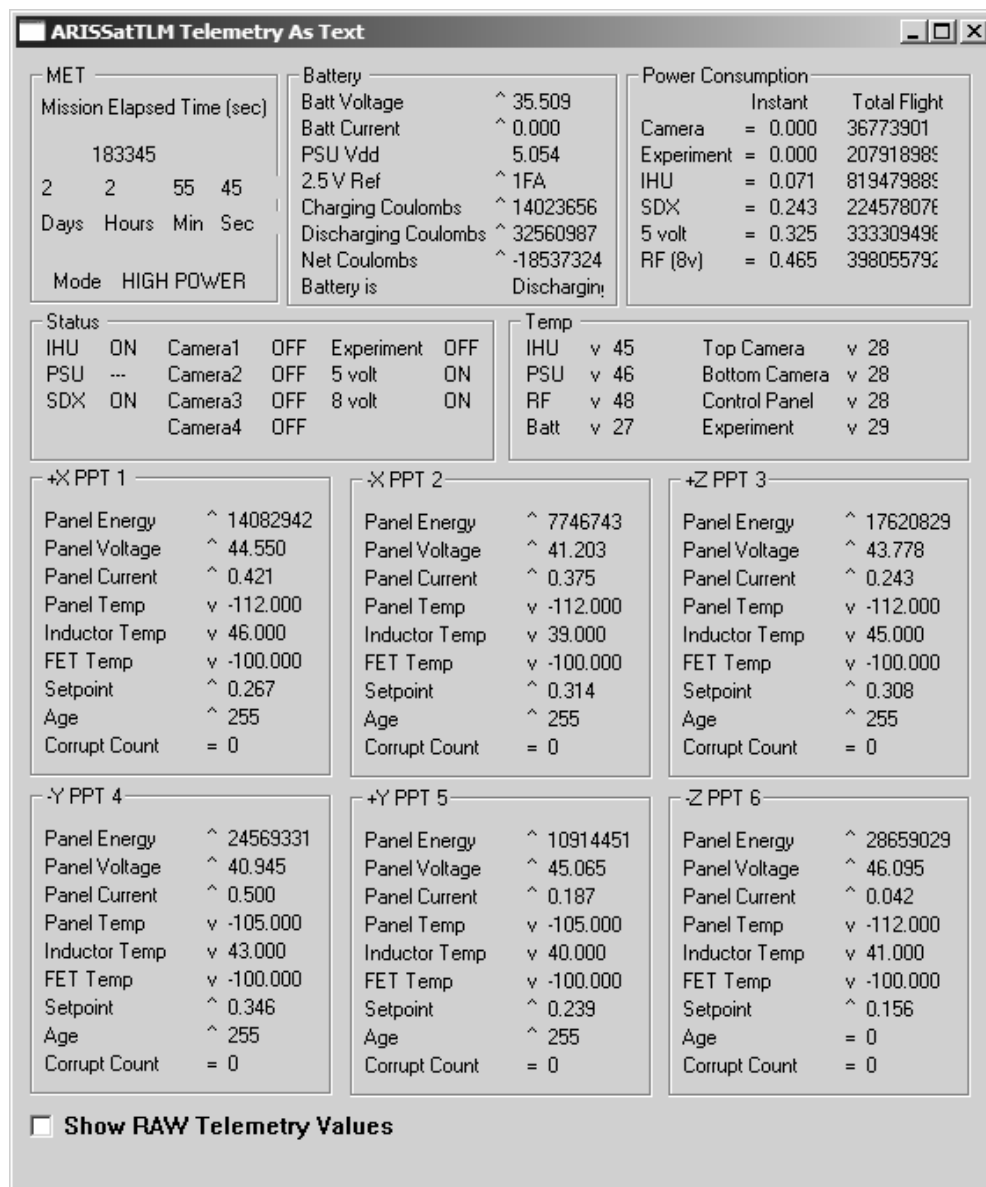


```
ARISSatTLM Version 0.32-DQ
File
ARISSatTLM Ready.
Select File/Open to decode a WAVE file.
Select File/Start to start the soundcard.
The expected size of the regular telemetry block (ss_telem_t) is 235 bytes.
DLL test passed.
Starting interprocess communications.
Inbound pipe created. Waiting for data coming through pipe...
Starting soundcard.

Packet received at 09:16:20. Length = 266 bytes.
000: 54 c0 40 00 00 48 69 2c 20 54 68 69 73 20 69 73      | T.@..Hi, This is
010: 20 41 52 49 53 53 61 74 2d 31 2e 31 cc 02 00 02      |  ARISSat-1.1....
020: 00 00 00 84 00 eb 00 e4 00 ed 00 ec 00 e9 00 ef      | .....
030: 00 8a 00 90 00 80 03 fa 01 fa 01 94 24 e5 fe ff      | .....$.
040: ff e8 fb d5 00 00 00 5b d7 f0 01 00 00 0d 20 31      | .....[..... 1
050: 02 00 00 00 00 20 8d 97 64 0c 00 00 00 00 51 45      | .....d.....QE
060: d8 30 00 00 48 30 1b e5 db 85 00 00 f6 30 48 fe      | .0..H0.....OH.
070: aa c6 00 00 49 31 65 7e 42 ed 00 00 d7 31 43 9f      | ....Ile~B....1C.
080: 0c 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00      | .....
090: c3 01 7e e3 d6 00 00 00 ff 30 af 8a 03 fd af 01      | ..~.....0.....
0a0: ad 87 ff 00 b7 34 76 00 00 00 ff 30 c0 aa 03 fd      | .....4v....0....
0b0: 80 01 a0 9f ff 00 a7 b9 80 0a 00 00 ff 30 b6 8f      | .....0..
0c0: 03 fd f9 00 aa 9c ff 00 08 d3 71 92 00 00 fe 30      | .....q....0
0d0: b3 99 03 fd ff 01 9f af ff 00 93 8a a6 00 00 00      | .....
0e0: fe 30 c4 a7 03 fd bf 00 af 79 ff 00 74 35 d2 aa      | .0.....y..t5..
0f0: 00 00 ff 30 c1 a1 03 fd 2b 00 b3 4f 00 00 cb 0d      | ...0.....+.O....
100: 3b ff e2 0e 1c 1c 23 72 f7 23                        | ;...00#r.#
```

Screenshot - ARISSatTLM main window (Windows Version)

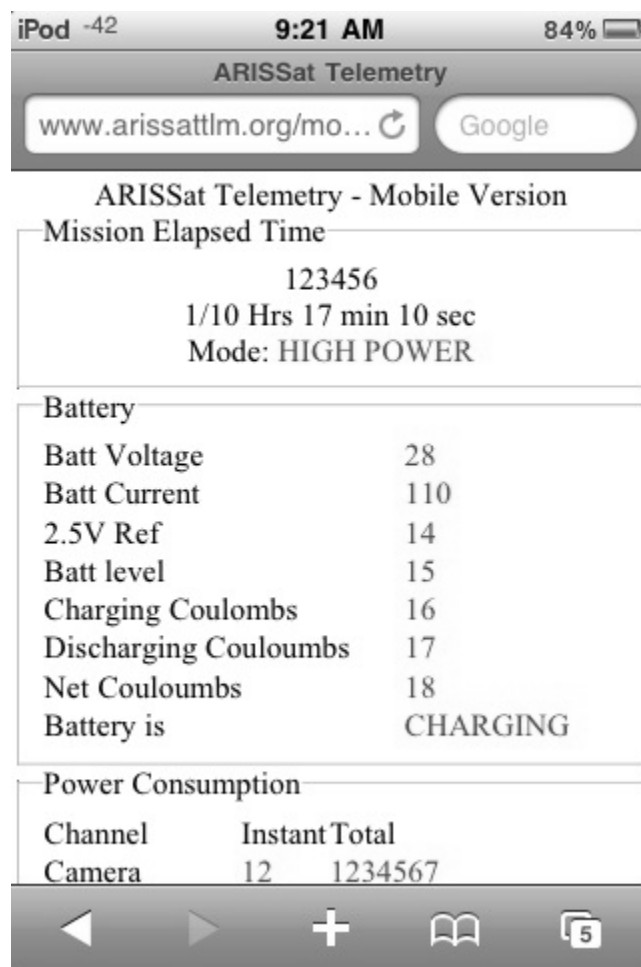
In this (earlier) version of ARISSatTLM the `ss_telem_t` struct was only 235 bytes. The `ss_telem_t` struct begins immediately after the ASCII "Hi" message. The Mission Elapsed Time starts at byte 0x01B in the hex dump. Note that the four bytes starting at byte 0x01B are "31 CC 02 00". As a four byte integer value this becomes 0x0002CC31, which converted to decimal is the Mission Elapsed Time of 183345 seconds (compare with "Telemetry As Text" screenshot below). The mission mode is the next four bytes are 0x00000002, which corresponds to "High Power".



Screenshot for Windows ARISSatTLM Telemetry As Text.

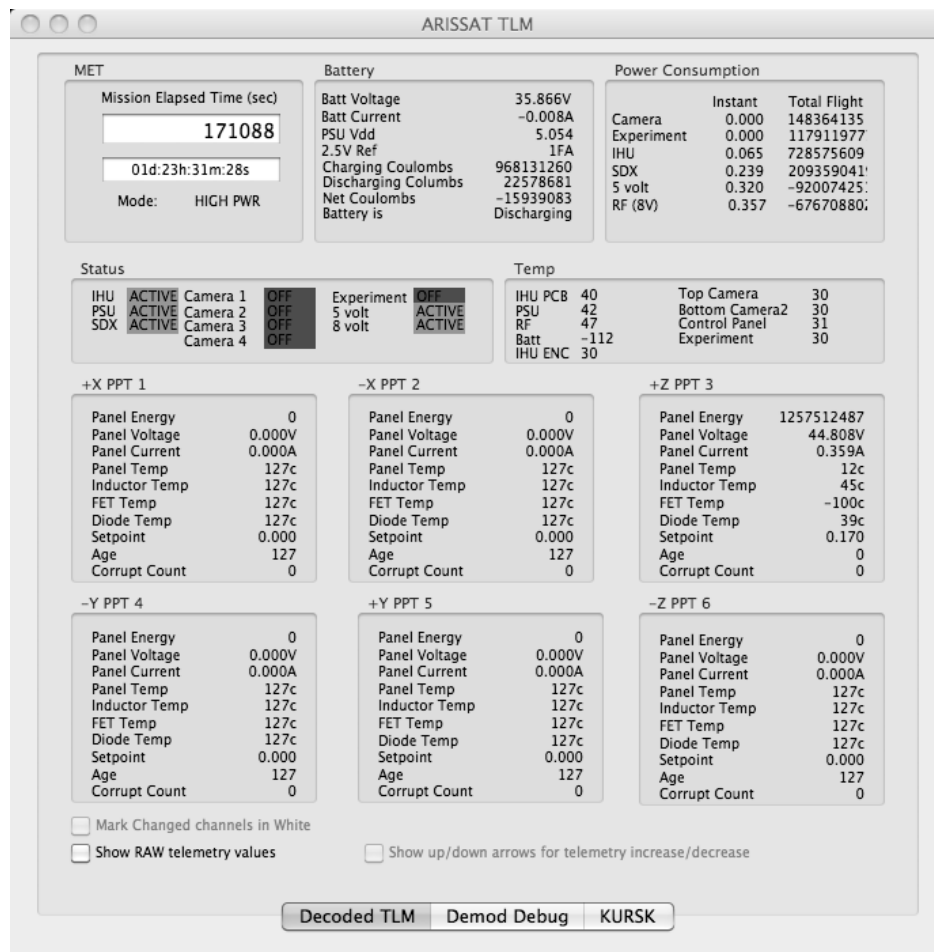
Compare with MAC ARISSatTLM screenshot.

The "^" and "v" characters indicate increasing or decreasing values compared to the previously received telemetry frame.



Screenshot - <http://www.arissattlm.org/mobile>

The layout for the telemetry values have been reformatted for display on smaller hand held devices.



Screenshot for Mac ARISSatTLM. Compare with Windows ARISSatTLM Telemetry As Text screenshot.

References

- 1 Monteiro, Anthony. "Space Radio for Windows." Proceedings of the AMSAT-NA 26th Space Symposium. 2008.
- 2 Karn, Phil. "The BPSK1000 Telemetry Modem for ARISSat-1." Proceedings of the AMSAT-NA 28th Space Symposium. 2010.
- 3 TortoiseSVN is available at <http://tortoisesvn.net/>
- 4 The format of the Kursk experiment data frame is documented on the SVN at <<https://svn.sarpeidon.net/viewvc/suitsat2/Experiments/Kursk%20011509/Suitsat%202/Structure%20of%20experiment%20data%20frame%2B.pdf>>
- 5 Karn, Phil. "The Satellite Telemetry Protocol (STP)". 8/1/2010. <https://svn.sarpeidon.net/suitsat2/repos/ground_station_software/ARISSatTLM/Documentation/telem.txt>
- 6 The task of calculating the exact time to transmit a telemetry frame given the frame size in bytes, factoring in the transmit bit rate, including the overhead for forward error correction, the CRC32, the two necessary HDLC flag bytes and any data dependent HDLC bit stuffing, is left as an exercise to the reader.
- 7 The author encourages constructive criticisms and particularly welcomes deconstructive comments and puns.

ARISSat-1 Power Management



by Anthony Monteiro, AA2TX
AA2TX@amsat.org

1 INTRODUCTION

ARISSat-1 uses an 825M3 silver-zinc battery from a Russian space suit and 6 solar panels to provide electrical power. In sunlight, the solar panels run the satellite and charge the battery. In eclipse, the satellite will run on the battery only. The power management function of ARISSat-1 is used to apportion the available electrical power amongst the various satellite subsystems. The two major concerns of power management are positive energy balance and battery life.

To have a positive energy balance, the energy provided by the battery during eclipse must be completely replenished during the sunlight charging operation. Otherwise, the battery will eventually become completely discharged during eclipse causing shut down of the satellite.

However, battery life is an even more important concern for ARISSat-1. Silver-zinc batteries are not typically used when a large number of charge/discharge cycles are required. This battery is specified for only 5 cycles but will see 16 cycles every day while in orbit. The only way to extend the number of cycles is to limit the discharge current of the battery. This is critical to the life of ARISSat-1 because as a silver-zinc battery fails it slowly short-circuits increasing the load on the power bus. When the battery has failed completely, it will appear as a dead short rendering the satellite inoperable.



825M3 Russian Space Suit Battery

2 Battery Overview

ARISSat-1 has an 825M3 Russian space-suit battery for storing power¹. This battery uses rechargeable silver-zinc (AgZn) cells. There is very little technical data available on this battery but the known specifications are as follows².

Cells per unit	18
Nominal voltage	27 V
Nominal capacity: Min.	14.0 Ah
Typical capacity	20.5 Ah
Charge method - Constant current	1 $\pm$ 0.2 A
Max. charge voltage	35.8 $\pm$ 0.15 V
Min. discharge voltage	20.5 $\pm$ 0.5 V
Full charge/discharge circles	5
Temperature range	+6 to +45 C
Min. pressure	1.33 x 10 ⁻⁶ Pa
Wet life	1 year

The specifications show that the 825M3 battery operating range is between +6 to +45 C. However, the thermal analysis of ARISSat-1 provided by Dick Jansson shows that the battery would be expected to stabilize at approximately -30 C. This is lower than the minimum specified operating temperature and will affect the capacity of the battery. There is no specific data available from the 825M3 manufacturer on operation below the specified temperature range.

Based on discussions with Yardney Technical Products, a company that manufactures similar silver-zinc batteries, the cold discharge performance of the 825M3 battery was estimated³. See Figure 1. The chart shows that the 825M3 battery should be able to provide at least 6 amp-hours of capacity when new, even at -30 C.

In order to help warm up the battery to improve its performance, a thermal blanket (MLI) will be employed. The battery will produce some heat internally from losses which will help to increase the operating temperature. These depend upon the state of charge and the charging rate. When new, it is estimated that the battery will produce 12 to 18 milliwatts of heat during discharge. During charge, the battery is estimated to produce between 20 to 140 milliwatts. An increase in temperature would significantly improve the battery capacity. At 25 C, the expected output voltage range would be between 28 and 33.5 volts.

There is no specific charge data available for the 825M3 battery but based on information supplied by Yardney, a charge curve was estimated as shown in Figure 2. This curve shows the battery terminal voltage as a function of its charge capacity. As shown in the figure, there is a noticeable voltage spike to about 36 V at approximately 30% of charge. This is typical of all silver-zinc batteries and is due to a chemical change in the electrodes

ARISSat-1 Power Management



from silver-oxide to silver peroxide at this point in the charge cycle. As the charge is increased, the battery terminal voltage will settle into the range of 34 to 35 volts until the battery is fully charged. When fully charged, the terminal voltage will be approximately 36 volts and is limited by the ARISSat-1 circuitry.

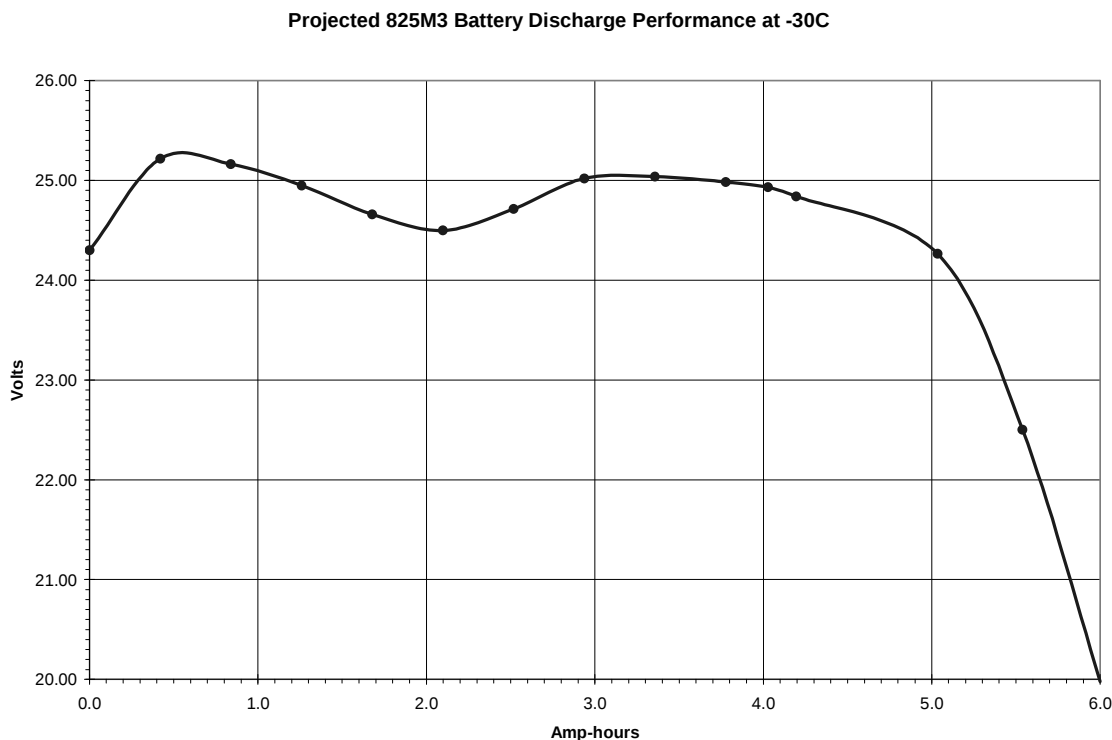


Figure 1. Projected 825M3 Discharge Performance

The charge efficiency (coulombic efficiency) of the battery is the discharge capacity of the battery in amp-hours divided by the amp-hours required to recharge it back to the fully charged state. The charge efficiency is not specified for the 825M3. A recent technical paper indicates a typical efficiency of 80%⁴. Other papers show a wide range from 63% to 98% but seems to be highly dependent on the number of cycles with the efficiency dropping with the cycle number. The silver-zinc battery used in the Mars Environmental Survey Mission showed an overall charge efficiency of 89% while being subjected to a simulation of the mission with a total of 30 cycles⁵. Since the charge efficiency is unknown and varies widely, the state of the battery cannot be accurately determined by the total charge delivered. In general, the charge state of a silver zinc battery is determined by the terminal voltage. For the purpose of predicting energy efficiency, the charge efficiency of the 825M3 was assumed to be 80%.

The *energy* efficiency of a battery is akin to the charge efficiency but is a measure of the total energy (watt-hours) discharged divided by the total energy required to fully recharge it. The 825M3 battery may provide a significantly lower discharge voltage (~24.5

ARISSat-1 Power Management



V) than the voltage required to charge it (~36 V) and so its energy efficiency is lower than its charge efficiency. Based on the projected charge and discharge data, the energy efficiency of the 825M3 battery is estimated at 54%.

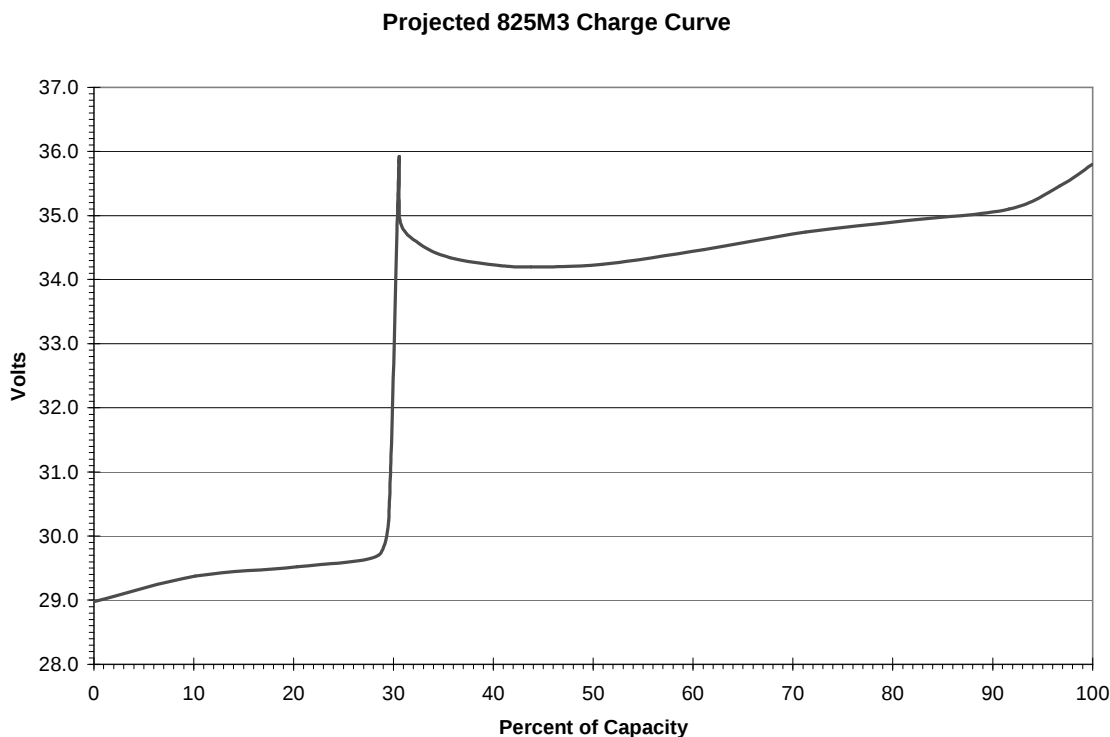


Figure 2. Projected 825M3 Battery Charge Curve

The expected battery failure mode is silver dendrite growth which causes *slow-shortening* through the electrode separator. The growth of the silver dendrites is caused by silver in solution being re-deposited on the silver electrode but in a different location than where it came from. This dendrite growth is a function of the depth of discharge and number of charge-discharge cycles. Projections from information provided by Yardney indicate that the battery should last for at least 500 cycles if ~7.5 watts are used during eclipse. This is approximately the average power needed to run ARISSat-1 in full power mode. At the typical 16 cycles per day, this would result in a battery life of approximately 1 month. Assuming a uniform dendrite growth rate, reducing the power to ~3.7 watts in eclipse would double the battery life to at least 2 months and hopefully much longer. When the battery has failed completely, it will appear as a short-circuit across the power bus rendering the satellite inoperable.

The operational limit of the 825M3 is the “wet-life” which is specified as one year from the time it is filled with electrolyte. The wet-life limit is caused by separator deterioration from exposure to the electrolyte solution. Since ARISSat-1 will re-enter in about one year, this is not expected to be a limiting factor.

3 Solar Panel Overview

The solar panels on ARISSat-1 were left-over from the NASA Small Explorer (SMEX) satellite series⁶. These solar panels are series connections of 50 individual solar cells. The panels each provide approximately 19.2 watts at 42 volts in full sunlight at 28 C⁷. The panels are specified to have no output loss after 1 year in low-earth orbit. As ARISSat-1 is expected to re-enter within about 1 year, solar panel degradation has not been taken into consideration.

The electrical curves for the SMEX panel are shown below in Figure 3. These are for full-sunlight illumination and at a temperature of 28 C. As seen in the chart, the voltage and power available from the solar panel is a function of the current drawn from the panel. This curve will vary with temperature and illumination.

Solar panels will produce a somewhat higher output voltage and thus more power at lower temperatures. The temperature coefficient of the SMEX panels is specified at .193% Voc/degree C. The ARISSat-1 thermal model indicates that the maximum temperatures expected on the solar panels while in the sun would be -15C to +35 C. This variation would have only a minor affect on the open circuit panel voltage and the corresponding power.

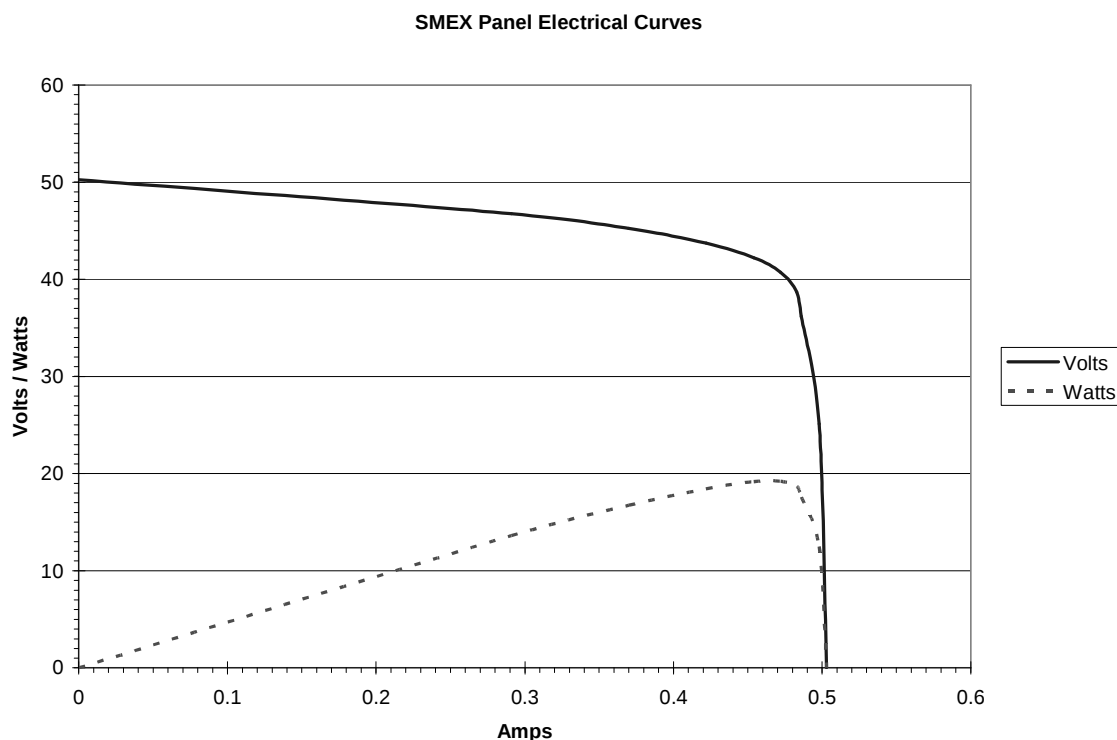


Figure 3. Full Sun SMEX Solar Panel Electrical Curves

ARISSat-1 Power Management



There are a total of six panels on ARISSat-1 with a panel on the top and bottom and one on each side. ARISSat-1 has protruding components including the handles and the antennas. These protrusions will cause shadows on the solar panels depending upon the sun (beta) angle. As ARISSat-1 has no attitude control, the orientation of the panels with respect to the sun and thus the shadow cast on the panels is uncontrolled. The SMEX panels are made of series connected cells which are very sensitive to shading. Fully shading a single cell will reduce the panel voltage and power output to zero.

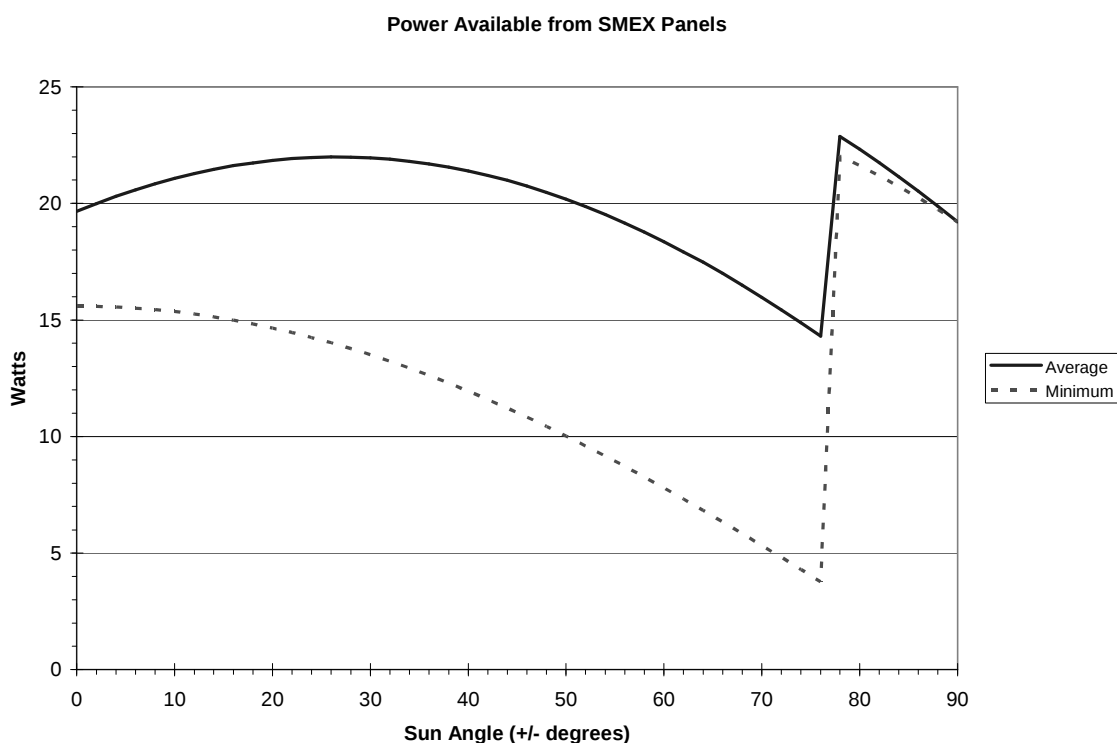


Figure 4. Power Available From SMEX Panels

The considerable skills of Bob Davis, our resident *EXCEL Wizard*, were called upon to develop a spreadsheet to combine the effects of the solar (beta) angle, shadowing from the handles and antennas, and the satellite rotation about the Z axis to predict the total solar illumination and the resulting available power. The results are shown in Figure 4. As can be seen from the chart, while a significant average power is available at all sun angles, the minimum power dips to less than 5 watts at around 70 degrees. This is the result of the antenna casting a shadow on the top (or bottom) solar panel. The solar angle runs from -90 (bottom) to +90 (top) degrees.

4 Maximum Power Point Tracker Operation

Each solar panel is connected to a maximum power point tracker (MPPT) circuit. The MPPTs are DC to DC converters that are designed to draw the maximum power available from each solar panel to drive the +28V bus. This is the main power bus and it is directly connected to the battery. In order to prevent over-charging the battery, the maximum voltage from the MPPTs is limited to approximately 36 volts.

The power output from an MPPT is a function of the maximum power available from its solar panel, the electrical efficiency and the tracking efficiency. The electrical efficiency is just the output power divided by the input power. For the ARISSat-1 MPPTs, the electrical efficiency was measured at 85% at full power.

The tracking efficiency depends upon how well the MPPT actually tracks the maximum power point of the solar panel. The MPPT dynamic response is shown in Figure 5. This shows the step response of the MPPT to a fully illuminated panel. The solid line is the solar panel current. The maximum power point current is reached in 120 milliseconds as shown in the chart. There is a small overshoot (not visible on the chart) and then a correction. The power output is shown in the dashed line. The power stabilizes in 140 milliseconds.

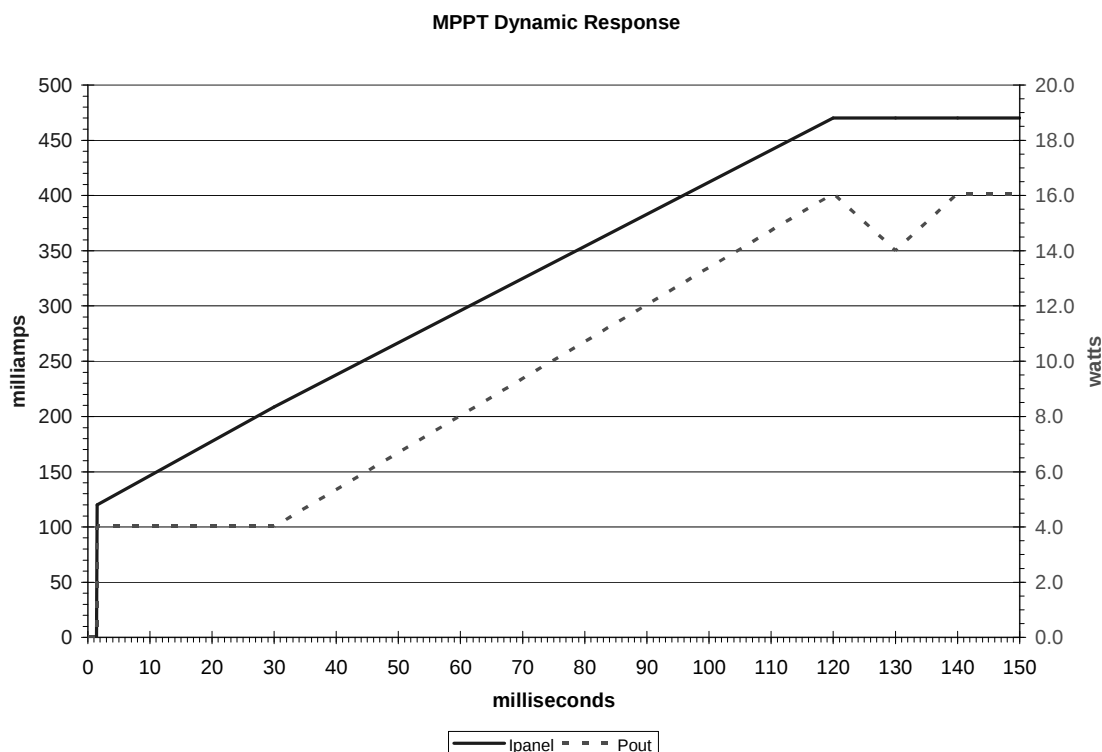


Figure 5. MPPT Dynamic Response

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The MPPTs are designed to respond very quickly to a drop in panel voltage. As tested, there was no significant delay in the downward tracking ability of the MPPTs.

As the satellite spins, the side solar panels will go in and out of the sun. The shading from the handles cause the panel illumination to change abruptly during a revolution. Similarly, the shading from the antennas can cause the power from the top and bottom panels to change abruptly. These effects challenge the dynamic tracking ability of the MPPTs and the corresponding power available from the MPPTs will decrease at high satellite spin rates.

This author developed a power system simulation program (in C++) to combine the solar panel illumination model from Bob Davis with a solar panel electrical model and an MPPT dynamic performance model. This was used to predict the output power from the MPPTs at various sun angles and at satellite spin periods of up to 4 seconds (i.e. 15 rpm.) This is 4 times faster than SuitSat-1 although ARISSat-1 is expected to spin at about the same rate. The MPPTs are sufficiently responsive that there is minimal loss of power from tracking error even at this rate. At very high spin rates, there would be significantly less power output from the MPPTs. The model predictions of the minimum and average power output from the MPPTs is shown in Figure 6.

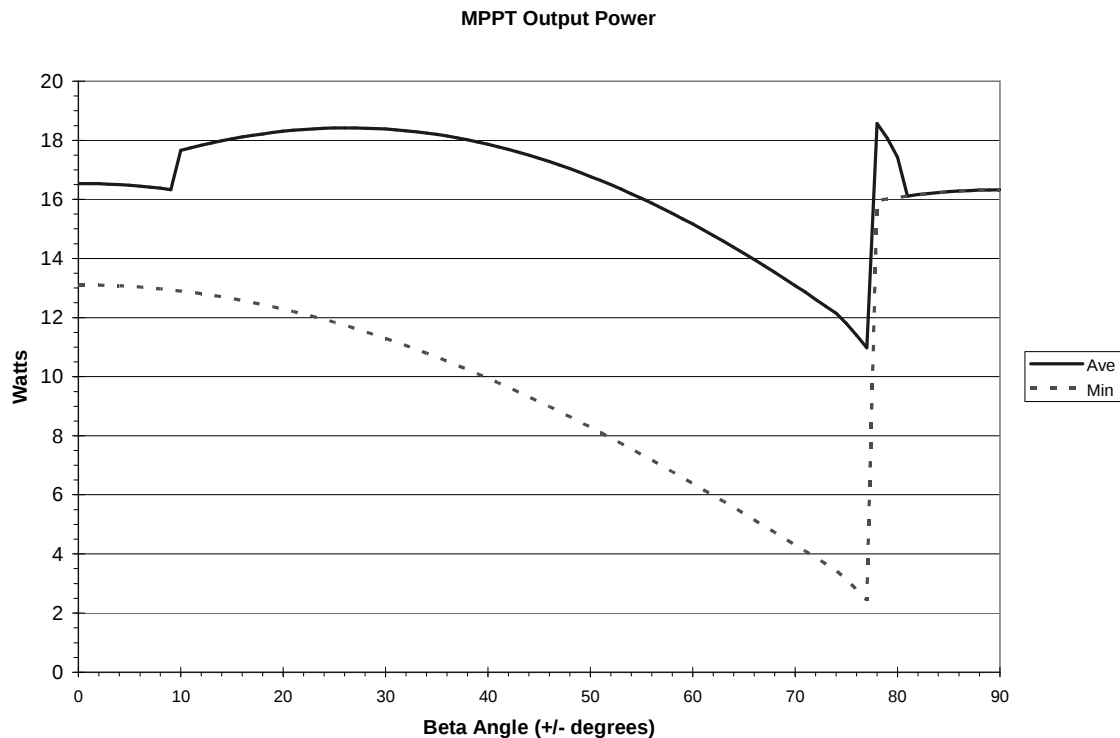


Figure 6. MPPT Output Power

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It is important to note that while the average power from the MPPTs over a rotation is always above 10 watts for all solar angles, the minimum can go as low as only 2.5 watts at around 76 degrees. This is the result of shadowing of the top (or bottom) solar panel from the antenna. If the satellite electronics requires more power than the MPPTs can provide, the power will be drawn from the battery. If the battery is unable to provide the extra power, the satellite will power down. This can happen even in full sunlight.

5 Power Control Overview

ARISSat-1 consists of several electronic circuits as shown in the table below.

Designation	Circuits
CAM	Cameras and Video Capture Circuit
CMD-RX	Command Receiver
COM-RX	Communications Receiver
COM-TX	Communications Transmitter
DTMF	Touch Tone Command Decoder
EXP	Kursk Science Experiment
IHU	Internal Housekeeping Unit
PANEL	Control Panel
PSU	Power Supply Unit
SDX	Software Defined Transponder

For the purpose of power management, the circuits are grouped into four operating functions as shown in the table below.

Function	Circuits
RX-MODE	CMD-RX, COM-RX, DTMF, IHU, PANEL, PSU
CAMERA	CAM
EXPERIMENT	EXP
TX-MODE	COM-TX, SDX

While ARISSat-1 is operating, RX-MODE will always be enabled. The CAMERA function is enabled when a new image is needed. The EXPERIMENT function is enabled to collect data for the Kursk experiment. TX-MODE is enabled when ARISSat-1 is transmitting its downlinks. The CAMERA, EXPERIMENT, and TX-MODE functions can be independently enabled as needed.

The nominal power required by each function is shown in the following table. This is measured at the battery terminals and includes the power supply efficiency. The power required varies somewhat with the battery voltage. It is also likely to be temperature dependent but this was not measured.

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Battery Voltage	RX-MODE		CAMERA		EXPERIMENT		TX-MODE	
	mA	watts	mA	watts	mA	watts	mA	watts
24 V	112	2.7	62	1.5	26	0.6	199	4.8
29 V	98	2.9	52	1.5	21	0.6	162	4.7
34 V	91	3.1	47	1.6	21	0.7	142	4.8
36 V	89	3.2	46	1.6	21	0.7	131	4.7

The RX-MODE function operates 100% of the time so its average power requirement is the same as in the table above. However, the CAMERA and EXPERIMENT are only turned on for a small portion of the time so the average power requirement is much less. The duty cycles and average power over 24 hours are shown below.

Function	ON time	Cycle Time	Duty Cycle	Average Power
CAMERA	8 seconds	120 seconds	6.67%	110 mW
EXPERIMENT	100 minutes	1 day	6.94%	50 mW

The TX-MODE duty cycle depends upon the power mode as discussed in the next section.

6 ARISSat-1 Power Modes

ARISSat-1 has three distinct power modes; *High Power*, *Low Power* and *Emergency Power*.

6.1 High Power Mode

In this mode, all of the satellite functionality will be operational. The experiment will be turned on for 100 minutes each 24 hour period. The SSTV system will be operational and will send an SSTV image about once every minute. The RF outputs will include the BPSK downlink (telemetry and experiment frames,) CW beacon, FM Audio/SSTV and the linear transponder. In HIGH POWER mode, the TX-MODE function operates all the time.

6.2 Low Power Mode

This mode is intended to reduce the power required but still provide useful satellite functionality. This is primarily achieved by reducing the duty cycle of the RF transmitter system. The CAMERA function will be turned off but stored SSTV image transmissions will continue. The experiment data collection will continue to operate if it was already started. The BPSK downlink will be limited to transmitting a single telemetry or experiment frame each time it is activated. The TX-MODE function is power-cycled to conserve battery power.

6.3 Emergency Power Mode

This mode is intended to extend the life of the satellite as much as possible when the battery failure is imminent. In this mode, the EXPERIMENT and CAMERA functions are turned OFF. There will be no SSTV or experiment frame transmissions. The BPSK downlink will be limited to transmitting a single telemetry frames each time it is activated. The TX-MODE function is power-cycled to conserve battery power.

6.4 Power Mode Functions Summary

The table below provides a summary of the functions provided during the various power modes.

Mode	TX-MODE ON Cycle	TX-MODE OFF Cycle	CAMERA	Experiment data collection	BPSK downlink frames
High	100%		*	*	Telem + Exp
Low	30 sec	120 sec		*	Telem + Exp
Emergency	30 sec	330 sec			Telem

6.5 Required Power

The power required to run the electronics is dependent on the power mode and to some extent the battery voltage. While the battery voltage can vary over a range for each power mode, typical values are shown. The table below summarizes the expected average and peak power required to run each mode.

Mode	Battery Volts	Peak Power (watts)	Average Power (watts)
High Power	36	10.2	8.1
Low Power	36	8.6	4.2
Low Power	34	8.6	4.1
Low Power	29	8.2	3.9
Emergency Power	24	7.5	3.1

7 Power Management Overview

The primary goal of the power management algorithm is to maximize the battery life while providing useful satellite operation. The way to maximize the battery life is to limit the battery discharge as much as possible so there is no single correct answer for this and tradeoffs need to be made.

The basic approach taken here is to always run *High Power* mode whenever this can be done without significantly discharging the battery. In sunlight, the solar panels and MPPTs provide sufficient power to run the electronics and charge the battery over most solar angles. Since the average power required to run the cameras is very low, the

ARISSat-1 Power Management



cameras are permitted to draw power from the battery without causing a power mode change.

A *Force High Power* mode command is also available which will allow a ground command station to force the satellite into *High Power* mode for about 30 minutes. Activation of this command should not be taken lightly but can be used occasionally without serious negative effects.

In eclipse, the satellite will switch to *Low Power* mode to provide a useful mission while reducing the discharge of the battery. This is done primarily by turning off SSTV operation and reducing the duty cycle of the transmitter. A single BPSK1000 frame takes 30 seconds to send so that is the length of time the transmitter is active in this mode. The linear transponder function does not significantly alter the power required so it can continue to operate while the transmitter is on. The transmitter cycle time was selected to allow reception of multiple transmissions per ground station pass.

The satellite will initially operate in *Low Power* mode from power-up. The 15 minute safety timer must expire before any transmissions are possible in any case.

If the battery voltage falls below 24 volts, the battery is nearing the end of its capacity. In this case, the satellite will switch to *Emergency Power* mode to further reduce the power required to operate. This is intended to give the satellite its best chance of making it through eclipse. The transmit duty cycle is low in this mode and was selected so that at least one telemetry frame could be received per satellite ground station pass. It is possible for the satellite to operate in this mode in eclipse yet switch back to *High Power* mode in sunlight if the solar angle is favorable.

The algorithm uses a number of enable and lockout timers to insure that the power modes transition smoothly and the modes do not oscillate. The selected power mode may change while the transmitter is on and sending missions. It is not intended that this transmission would be disrupted. The currently selected missions should be completed and the new power mode used in scheduling the next set of missions. This does not apply to the experiment. If *Emergency Power* mode is selected, the experiment operation shall be terminated immediately. The experiment can be restarted on its normal schedule only if the satellite is no longer in *Emergency Power* mode.

8 Power Management Algorithm

The only reliable indicator of the battery state is the terminal voltage so this is the major input to the algorithm. The selected power mode also depends upon whether the battery is being charged or discharged and what functions are currently operating so this information is also needed.

This algorithm is shown in *c-like* pseudo code. This is intended to allow a precise representation of the desired behavior. It is not intended to provide any specific guidance or constraints on the implementation of the actual software.

```
//***** Power Management Algorithm *****
```

```
// Output:
```

```
PowerMode = { HIGH, LOW, EMERGENCY };
```

```
// Input Parameters:
```

```
ForceHighPower;           // TRUE or FALSE
TxPTT;                     // TRUE or FALSE
CamerasOn;                 // TRUE or FALSE
BatteryVoltage;            // volts
BatteryChargeDelta;        // mA-sec over last 1 second
```

```
// Constants:
```

```
EMERGENCYVOLTS      = 24 Volts;           // Emergency threshold
MINHIGHVOLTS        = 34 Volts;           // minimum for high power
FULLCHARGEVOLTS     = 36 volts;
MINBATTERYCHARGE    = 150 mA-seconds;     // for positive energy balance
MINLOWENABLECOUNT  = 28 seconds;
MINHIGHENABLECOUNT = 28 seconds;
HIGHLOCKOUTCOUNT   = 1200 seconds;       // prevent retry for 20 minutes
FORCEHIGHCOUNT     = 1800 seconds;       // forced high lasts 30 minutes
```

```
// Static variables:
```

```
PowerMode           = LOW;                // Initial Power mode is LOW
ForceHighCounter;
HighEnableCounter;
HighLockoutCounter  = 900 seconds;         // power up lockout = 15 minutes
LowEnableCounter;
```

ARISSat-1 Power Management



```
// Process (runs every 1 second)
PowerMode PowerModeControl(ForceHighPower, TxPTT, CamerasOn,
                           BatteryVoltage, BatteryChargeDelta) {

    // if High power is commanded, just do it
    if (ForceHighPower) {
        ForceHighCounter = FORCEHIGHCOUNT;
        PowerMode = HIGH;
        return PowerMode;
    }

    // Check timer for forced high power
    if (ForceHighCounter) {
        --ForceHighCounter;
        return PowerMode;
    }

    // Switch to emergency mode immediately if battery is low
    if (BatteryVoltage < EMERGENCYVOLTS) {
        PowerMode = EMERGENCY;
        return PowerMode;
    }

    // See if we should change the current power mode
    switch(PowerMode) {

    case EMERGENCY:

        // See if we can switch to LOW power mode
        // Only change if battery stays high enough during PTT
        if (TxPTT) {
            if (BatteryVoltage > EMERGENCYVOLTS) {
                LowEnableCounter++;
            }
            else {
                LowEnableCounter = 0;
            }
        }
        else {
            // PTT is now off
            // Check low enable counter to see if we can switch
            // to LOW power mode
            if (LowEnableCounter >= MINLOWENABLECOUNT) {
                PowerMode = Low;
            }
            LowEnableCounter = 0;           // reset for next time
        }
        break;
    }
```

ARISSat-1 Power Management



case LOW:

```
// Check HIGH power lockout counter
// If still counting, no change
if (HighLockoutCounter) {
    --HighLockoutCounter;
    break;
}

// See if we can switch to HIGH power mode
// Only change if battery good during PTT
if (TxPTT) {
    // if battery voltage is fully charged or
    // battery is above high threshold and charging
    // with enough current then increment enable counter
    if ( (BatteryVoltage >= FULLYCHARGEDVOLTS) ||
        ((BatteryVoltage >= MINHIGHVOLTS) &&
         (BatteryChargeDelta >= MINBATTERYCHARGE)) ) {
        HighEnableCounter++;
    }
    else {
        HighEnableCounter = 0; // if not reset counter
    }
}
else {
    // PTT now off. Check High enable counter to see
    // if we can switch to HIGH POWER
    if (HighEnableCounter >= MINHIGHCOUNT) {
        PowerMode = HIGH;
    }
    HighEnableCounter = 0; // reset for next time
}
break;
```

ARISSat-1 Power Management



```
case HIGH:

    // If the Cameras are on, just return for now.
    // Since average power is really low, we will allow
    // Cameras to discharge battery a little
    if ( CamerasOn ) {
        break;
    }

    // if battery voltage is fully charged or
    // battery is above high threshold and charging
    // with enough current, then stay in High power mode
    if ( (BatteryVoltage >= FULLYCHARGEDVOLTS) ||
        ((BatteryVoltage >= MINHIGHVOLTS) &&
         (BatteryChargeDelta >= MINBATTERYCHARGE)) ) {
        break;
    }
    else {
        // Otherwise, switch to low power
        // mode and lockout switching back for a while
        PowerMode = LOW;
        HighLockoutCounter = HIGHLOCKOUTCOUNT;
    }
    break;

} // end switch()

return PowerMode;          // New power mode selected

}
```


9 Energy Balance

When in sunlight, the MPPTs provide power to run the electronics and charge the battery. In eclipse, all of the power to run the satellite comes from the battery. The satellite cannot use more total energy than it gets out of its Solar Panels and MPPTs or it will eventually run down the battery and power itself off during eclipse.

First, we need to calculate how much energy is needed during eclipse. In general, the satellite will operate in *Low Power* mode in eclipse. For the expected orbit of ARISSat-1, the eclipse time is about 37 minutes. The worst case power usage will occur when the battery voltage is at its maximum and a fully charged battery can produce up to about 34 volts. From the chart in section 6.5, *Required Power*, the average power required will be 4.1 watts. The total energy needed from the battery in eclipse is calculated by multiplying the average power by the discharge time as follows:

Average power used in eclipse	= 4.1 watts
Eclipse period	= 37 minutes
Energy needed from battery	= 2.5 watt-hours

The energy available from the battery during eclipse depends upon the power that was used by the electronics when the satellite was in sunlight. For the expected orbit of ARISSat-1, the sunlight time is about 53 minutes.

The power used by the electronics depends upon the battery voltage and the selected power mode. The worst case power use is at the maximum battery voltage which is 36 volts. From the chart in section 6.5, *Required Power*, the average power required will be 8.1 watts in *High Power* mode and 4.2 watts in *Low Power* mode. The total energy needed for the electronics while in sunlight is calculated by multiplying the average power by the discharge time as follows:

Average Power required in <i>High Power</i> mode	= 8.1 watts
Sunlight period	= 53 minutes
Energy required	= 7.2 watt-hours
Average Power required in <i>Low Power</i> mode	= 4.2 watts
Sunlight period	= 53 minutes
Energy required	= 3.7 watt-hours

The power produced by the MPPTs but not required by the electronics is available to charge the battery. The battery energy efficiency was estimated at 54%. This means that for every 1 watt-hour used to charge it, 0.54 watt-hours is available for discharge. The power available from the MPPTs depends upon the solar angle as was shown in Figure 6. The energy balance is shown in Figure 7. This is for satellite spin rates of up to 16 rpm. The dashed line shows the energy required and it drops between 52 and 76 degrees

ARISSat-1 Power Management



because the satellite will switch to *Low Power* mode at these angles. The solid line shows the average energy available from the MPPTs over one orbit.

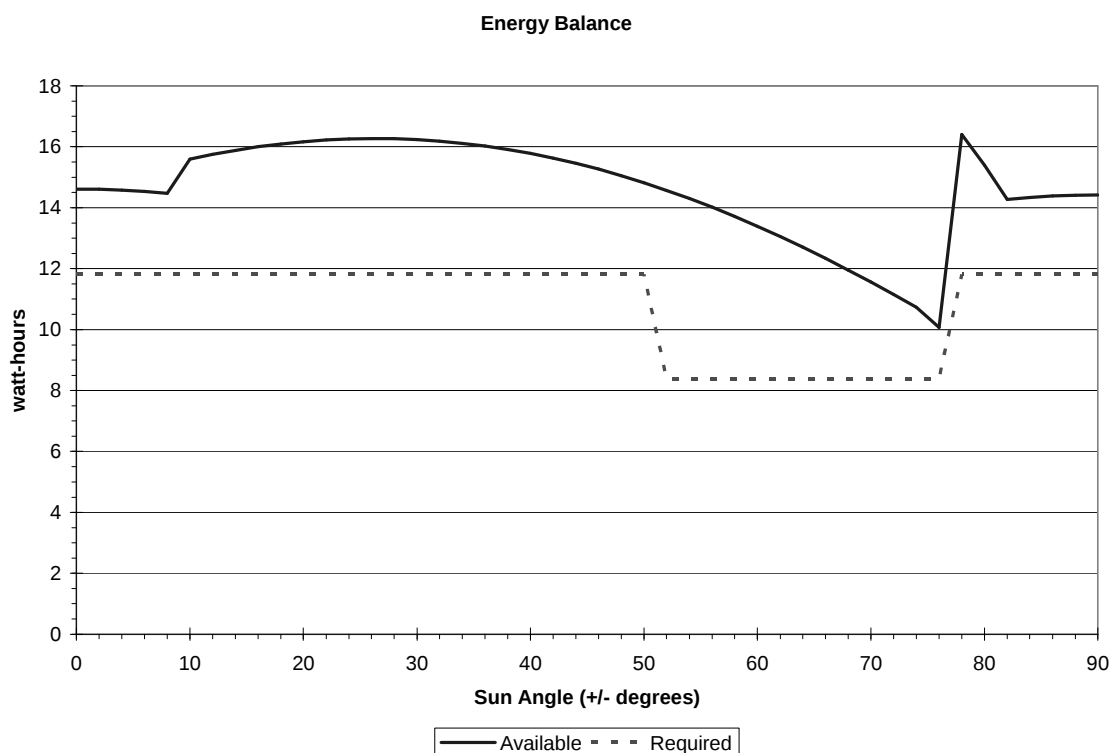


Figure 7. Energy Balance

As can be seen in the chart, the power management algorithm will insure that there is always a positive energy balance. As long as the battery is reasonably functional, the power required in eclipse can be provided during sunlight. The only caveat is that this calculation uses the average power available from the MPPTs. If for some reason, the satellite is not spinning at all (or is spinning extremely slowly,) the minimum MPPT output power could be less than the minimum required to run the electronics even in *Emergency Power* mode. There is no way to compensate for this.

Additionally, the satellite spin axis is predicted to be 10 degrees off from its Z-axis. This means that the beta angle will vary as the satellite spins. While the average power illuminating the solar panels would be the same over the entire range of solar and spin angles, there *may* be some additional combinations where there is enough total shadowing of the solar panels that the MPPTs cannot produce enough energy to run the electronics in full sunlight. This will cause a switch to *Low* or *Emergency Power* mode.

10 Failure Conditions

10.1 Battery Failure

The battery is required to power-up the satellite and must continue to operate for 15 minutes to insure that the solar panels are switched on. Failure of the battery within the first 15 minutes of power-up would result in complete loss of the mission.

The Kursk experiment requires continuous operation through eclipse so it will cease to function correctly when the battery can no longer hold an adequate charge.

The battery is expected to last for at least 8 weeks of normal operation. After this time, the battery will degrade and may fail to hold a charge. The power management system will attempt to extend the satellite operation through eclipse with a weak battery and to operate as much as possible with a failed battery while in sunlight. At that point, the safety timer circuit will reset when the satellite enters eclipse which will prevent operation of the radio transmitter for the first 15 minutes after re-entering sunlight. At sun angles outside the range of about 52 to 76 degrees, solar panel shadowing could cause the safety timer circuit to reset even in full sunlight effectively preventing any transmitter operation.

Should the battery fail completely, it will short out the power bus and the satellite will cease to operate.

10.2 Solar Panel Failure

If a solar panel is damaged or its associated MPPT circuit fails, the satellite will continue to operate on the remaining panels. This operation requires the battery to fill in as needed for the dead panel/MPPT in sunlight. While this condition will be detected and would cause a switch to *Low Power* mode, it may shorten the battery life and could result in a negative overall energy balance.

10.3 PSU/IHU Link Failure

If the PSU/IHU communications link fails, the PSU will turn off the cameras and the experiment and turn on the SDX and RF transmitter. The IHU will not be able to control power under this condition and will instead operate as if in *Full Power* mode but without the experiment or SSTV. This condition would likely cause premature battery failure.

11 Summary

ARISSat-1 will automatically manage its own power to maintain a positive energy balance and to promote extending the battery life of its silver-zinc battery. This is very important because battery failure would likely cause the satellite to cease functioning even in full sunlight. Silver-zinc batteries are not generally used when a large number of charge-discharge cycles are needed so in order to extend the battery life, the power management algorithm will attempt to discharge the battery as little as possible while still maintaining a useful mission.

ARISSat-1 will generally operate with a 100% duty cycle of the RF transmitter in sunlight and will switch to about a 20% duty cycle when in eclipse. Should the battery run down too far, it will switch to about a 10% duty cycle to attempt to extend the operation of the satellite as much as possible. The power management function should allow the battery to last for at least 8 weeks and hopefully until re-entry.



¹ The satellite was originally named *SuitSat-2* and was based on a Russian space suit.

² 825M3 Accumulator Battery Specification (pdf) provided by Lou McFadin, 1/16/2010

³ Private email and phone conversations with Tony Aretakis and the staff of Yardney Technical Products.

⁴ *Survey of Rechargeable Battery Technology, Report to Lawrence Livermore National Laboratories*, by A.D. Little, Inc. Cambridge, MA 1993.

⁵ *Battery Definition for the MARS Environmental Survey Mission (MESUR) Pathfinder*, by S. Dawson, D. Perrone, B. Otzinger, S. Di Stefano. Jet Propulsion Laboratory, California Institute of Technology 1994.

⁶ *SMEX-Lite Modular Solar Array Architecture*, by John W. Lyons. NASA Goddard Space Flight Center, Code 563, Greenbelt, MD 20771 (IECEC2002)

⁷ *STATEMENT OF WORK FOR THE SMEX•LITE MODULAR SOLAR ARRAY PANELS*, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, MD 20771

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AMSAT FOX Preview



Tony Monteiro, AA2TX
AMSAT Space Symposium 2010

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Background



- AMSAT Echo (AO-51) is the most popular ham satellite
- Can be worked with simple equipment
- 6 years old and starting to show its age
- Need succession plan

• • • • • • • •

⋮

Background



- But, launch costs keep going up
- Microsats (AO-51) were once the low-cost path to orbit – *not any more!*
- AMSAT can no longer afford to launch a microsat like AO-51

⋮

Launch Strategy



- Future good fortune ☺
- Rideshares (but no luck so far...)
- Take advantage of low-cost paths to orbit that exist today
 - ARISS (but low altitude = short lifetime)
 - CubeSat

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CubeSat



- Small satellite standard
- Developed by Stanford and Cal-Poly
- Intended to allow universities to be able to afford a satellite launch
- Standard deployment scheme (P-Pod) allows for pooled launches

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CubeSat Advantages



- Large and growing technical community (Boeing)
- Regularly scheduled launch opportunities
- Low-cost
- NASA Launch Initiative

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⋮

Major Technical Challenges



- Very small size
 - 10 cm cube $\approx 4'' \times 4'' \times 4''$
 - $\approx 1/16$ size of AO-51!
- Weight limit
 - $1.33 \text{ kg} < 3 \text{ lbs}$
- Limited solar panel area
- Limited real-estate for antennas

⋮

Technical Strategy



- Miniaturized electronics
- Lithium batteries to save weight
- Low power designs
- High-efficiency solar cells
- High-efficiency power system (MPPT)
- Deployable solar panels
- Deployable antennas

...

CubeSats are not a dead end!



- Stacked Cubes up to 3U
- Inflatable antennas
- Active attitude control
- 3-axis stabilization
- Micro propulsion

...

AMSAT Challenges



- CubeSat success rate < 50%
- Project planning and communications
- Volunteer development team
- Geographically dispersed

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AMSAT *FOX* Project Goals



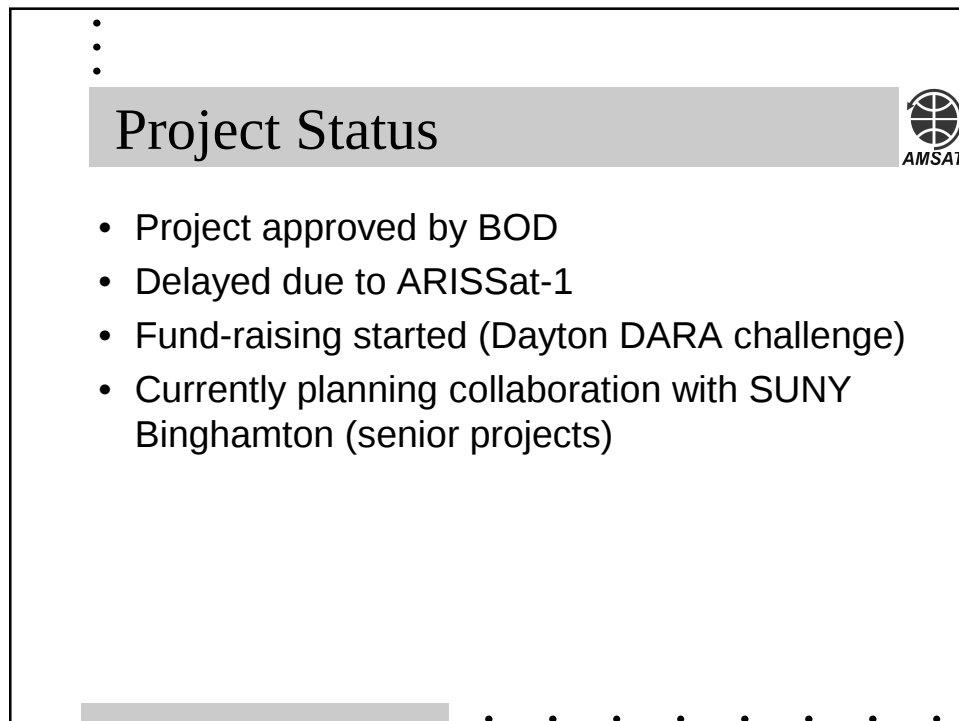
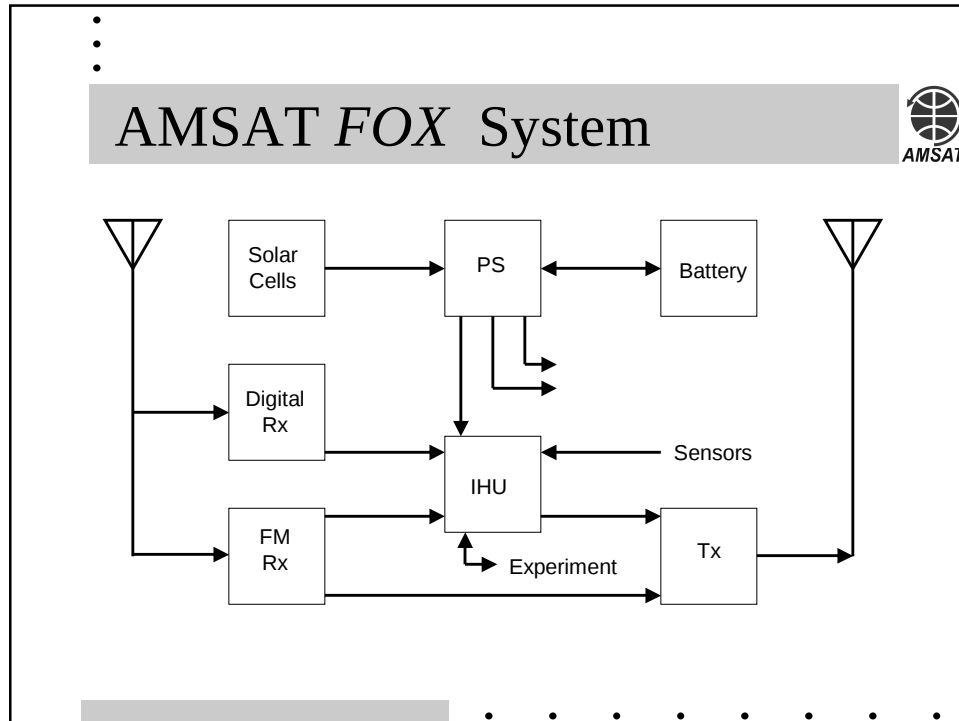
- Provide reliable communications via HT + hand-held Yagi (*a la AO-51*)
- Develop re-usable CubeSat satellite bus
- Promote education outreach via closer relationships with universities (SUNY+)
- Improve AMSAT engineering practices

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AMSAT *FOX preliminary specs*



- 600 – 800 km altitude orbit
- FM Transponder
- Mode U/V (mode B)
- Digital downlink (telemetry)
- Digital uplink (command)
- 500 mW transmitter
- Deployable solar panels
- Passive magnetic stabilization
- Possible science or technology experiment



...

SUNY Student Projects



- Space frame with deployable panels
- Deployable antennas
- Power system
- IHU
- Attitude determination and control

...

Hey! Ever want to...



- Design/build cool stuff?
- Mentor university students?
- Work on a real satellite?

...

More Opportunities



- Project Planning
- RF System design
- Thermal design
- IHU Software development
- PC board layout and construction
- Test planning and system testing
- Test equipment development
- Satellite construction
- Ground station software development
- ... and lots more!

...

...



Any Questions?



TNX de Tony, AA2TX
AA2TX@amsat.org

...

AO-51 Battery Capacity and Spin Trends

Presented by Mark Hammond N8MH and Colin Hurst VK5HI.

Introduction

Trends that have been of ongoing interest to the AO-51 Operations Group are those of Battery Voltage, Battery Capacity, Spin Rate and Temperatures. This presentation outlines the long-term trends that have been noted for Battery Capacity and Spin Rate, tabulated since the 1st January 2005.

Historical Clarifications on AO-51

Since the launch of AO-51 in June 2004, the various command stations that have been given the responsibility to maintain its longevity, have been involved in continuous monitoring and analysis of the Real-time Telemetry and the Whole Orbit Data (WOD). There have been periods where this has necessitated daily analysis and modifying on-board parameters.

In August 2006 a series of tests were conducted to clarify a number of concerns in respect to the performance of AO-51. One conclusion that was drawn at that time was that Radio Frequency Interference (RFI) from the Mode U Transmitters was affecting the performance of the Battery Control Regulator (BCR). Since August 2006, the BCR performance appears to have deteriorated further, which has resulted in a level of overcharge of the batteries. The BCR issue, coupled with the Total Illumination Periods that have occurred during 2008, 2009 and 2010, have required numerous innovative approaches on behalf of the command stations, to maintain continuous operation of AO-51. It is not the intention of this paper to elaborate on those procedures, but to identify the trends since January 2005. The trends have been compiled using the WOD's from AO-51. Since November 2006, the WOD's have been scheduled on an almost daily basis. Generally the WOD's are collected using 5, 30 or 60 second sampling periods.

Battery Capacity

The battery pack on AO-51 consists of 6, 1.2 Volt 4 Ampere-Hour Ni-Cad cells. On advice, AO-51's command stations have only ever cycled AO-51's batteries on the float charge section of a Ni-Cad charge/discharge curve. That is from a nominal 1.2 Volts to the Maximum charging voltage.

With reference to Figure 1, which shows the battery discharge profile on the 16th January 2005, during an eclipse of 32 minutes duration, we can make a number of observations.

- Cells 1, 2, 3 and 4 demonstrate similar discharge capacity.
- Cell 5 appears to demonstrate a higher capacity
- Cell 6 appears to be an under-performing cell.

One may argue that the calibration of the various cells was not optimal (an argument that has been previously raised), however for the purpose of this paper it is accepted that the respective Voltage and Current calibration values were correct at launch.

Battery Capacity

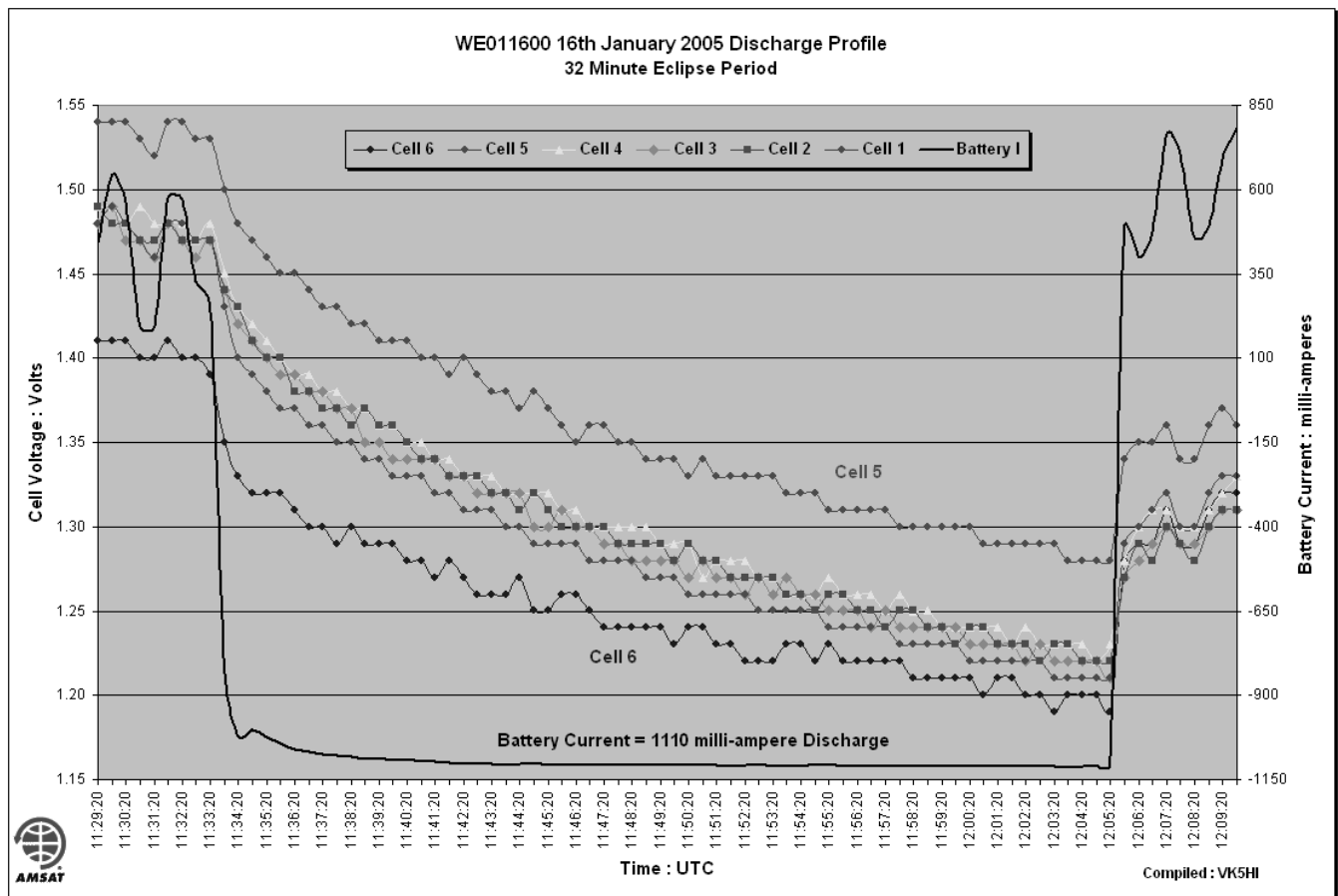


Figure 1.

To describe past Battery Discharge trends we will use the Energy term Joule. One Joule = One Watt-Second. Battery Voltage is not a true indicator of the health of a battery, whereas if we use Discharge Energy we can truly represent the health of the Battery.

The Discharge Energy (Capacity) can be readily calculated from the WOD's, using the procedure outlined in Appendix A. All the values quoted throughout the presentation have used this procedure.

Using the WOD, we011600 of the 16th January 2006 from which Figure 1 was derived we can make the following Calculation, to ascertain the Maximum Available Capacity..

At the time of entering eclipse the Total Battery Voltage was 8.81 Volts.

The Battery was fully charged, because of the ongoing BCR issue.

From the following calculation we note that the available Discharge Capacity is 21,100 Joules.

The calculation is the Average of the Cell Voltages (8.81 divide 6) multiplied by the Battery Capacity in Ampere-Seconds (4 AH x 3600 seconds) = 21,100 Joules.

Later in this paper we will highlight that the Total Discharge during this 32 minute Eclipse Period was 15,587 Joules.

Battery Capacity

Now we will advance five and a half years to the 9th May 2010.

During that five and a half year period, AO-51 has endured 3 Total Illumination Periods.

They were nominally from the 5th January 2008 to 9th April 2008, approximately 3 months. Then from 18th August 2008 to 7th May 2009 a period of 9.5 months. Finally 30th July 2009 to 30th April 2010, a period of 9 months. From the 5th January 2008 to the 30th April 2010, AO-51 was Totally Illuminated for 21.5 months out of 28 months, 77% of that period.

Fortuitously (from a telemetry point of view) AO-51 encountered a low-voltage trip at 00:06 UTC on the 10th May 2010, (during an 8.4 minute eclipse period) which has allowed the calculation of a definitive Battery Capacity, (following the third total illumination period).

The following graphic, Figure 2 highlights the low-voltage trip at 00:06 UTC.

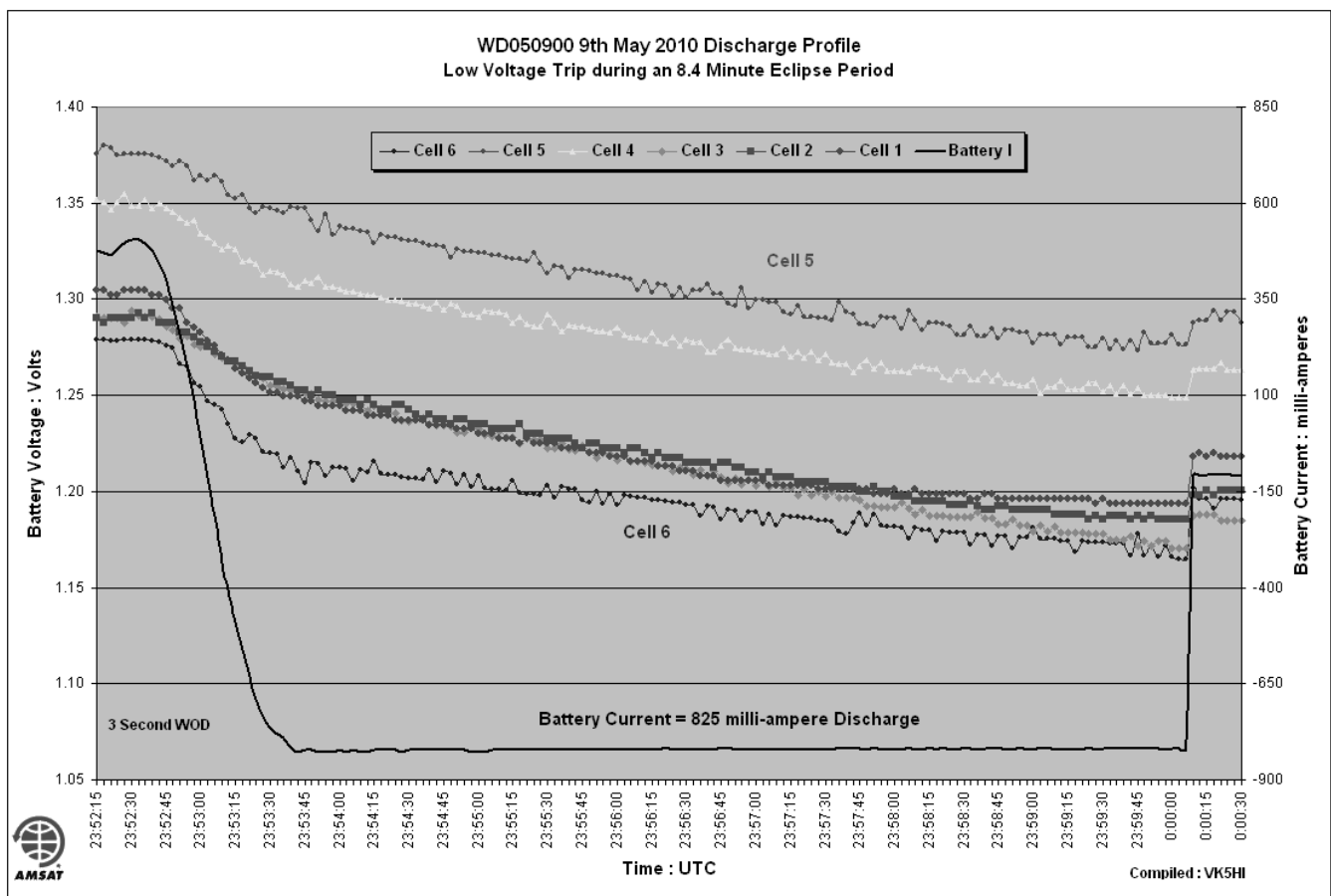


Figure 2

Fortunately this graphic being obtained from a 3 second WOD, allows us to calculate the Battery Capacity with a high level of confidence.

At the point of entering the eclipse period the maximum Battery Voltage was 7.87 Volts as compared to 8.81 Volts in January 2005, which indicates a degree of degradation of all the six Ni-Cad Cells.

Battery Capacity

Observations from Figure 2 include

- Cells 1, 2 and 3 have degraded to a greater extent than Cell 4.
- Cell 5 although degraded still demonstrates a higher capacity relative to the other cells
- Cell 6 continues to be the under-performing cell.

Calculation of the effective Maximum Battery Capacity from the WOD Data WD050900, amounts to a value of 2500 Joules. This was calculated from the point of entering the eclipse period until the low-voltage trip occurred. This calculation is as per the procedure outlined in Appendix A.

All the WOD's are available for download as per Bibliography Note 3, should you wish to do follow-up analysis.

Hence we have degradation over five and half-years from a nominal capacity of 21,100 Joules to 2,500 Joules. This means that as at 9th May 2010 we only had 12% of the original battery capacity.

Now we will review the historical trends over the 2005 to 2010 period.

Historical Battery Discharge Trend

To explain the historical trend of Actual Battery Discharge, we will present it in 3 stages.
Prior to the total illumination periods, inclusive of the total illumination periods, and finally one of the battery status as at 9th May 2010.

- Prior to Total Illumination Periods

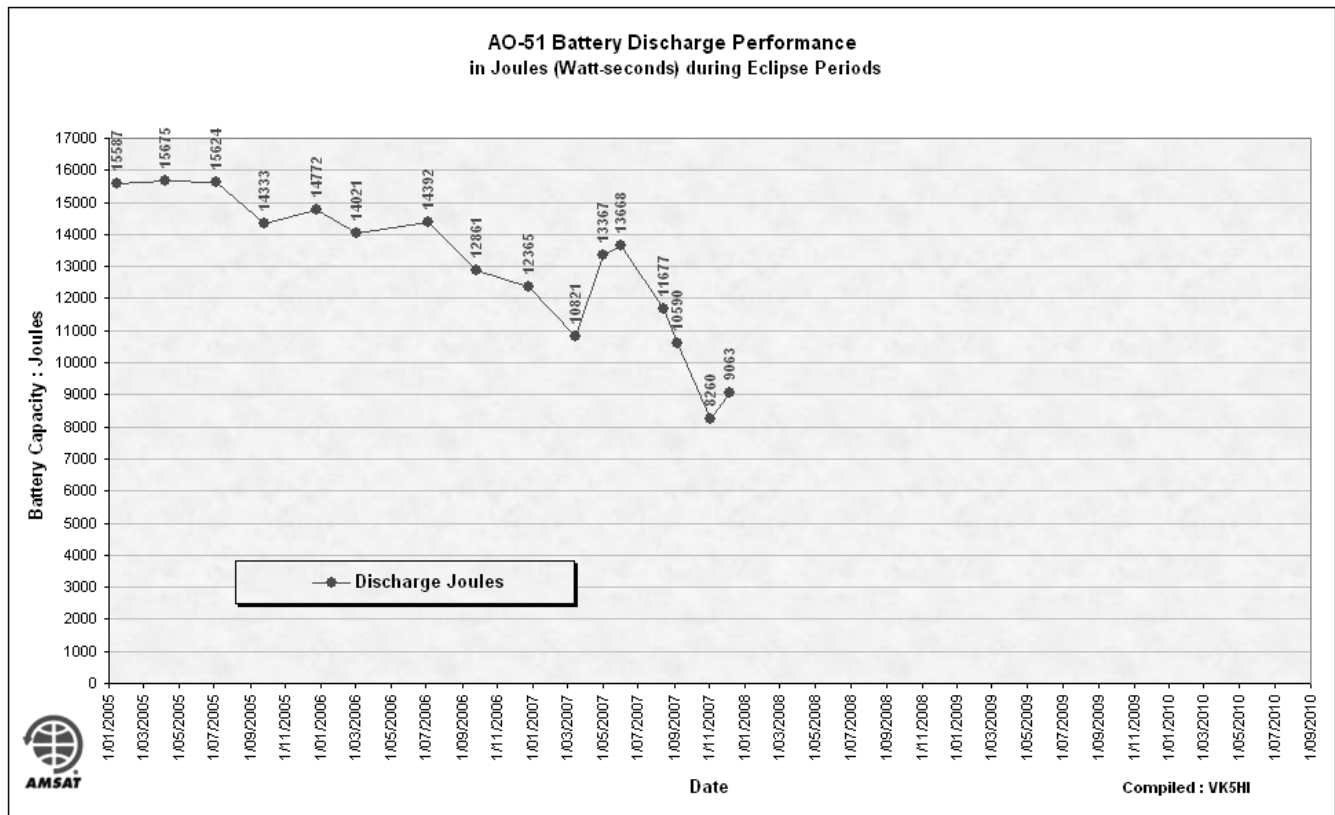


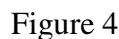
Figure 3

Figure 3 highlights the Period Prior to the Total Illumination Periods

Looking at this graphic a question arises. What is the trend of the discharge curve?

- During the period 2005 to 2007, the command stations experimented with different power budget scenarios to ascertain the optimal operating parameters for AO-51. Of paramount importance was the battery performance.
- The “humps and bumps” are the result of the command station experimentation. The objective being optimal downlink power whilst maintaining a safe level of battery voltage.
- The net downward trend of the graphic is clear, and approximates to a second order polynomial, shown later in this presentation.

- Inclusive of the Total Illumination Periods



At the conclusion of the Total Illumination Period #1 in 2008, the command stations became acutely aware of a level of degradation of the Battery Capacity. The maximum capacity available during the following eclipse periods was nominally 9,700 / 9,800 Joules, compared to 21,000 in January 2005. A reduction of 55%.

In both of the above observations the Battery Discharge values are the result of the command stations setting what they consider to be the safest and optimal parameters for AO-51.

At the conclusion of the Total Illumination Period #3 of 2009/2010 the Battery Capacity had degraded to a level that Transmit Operations during increasing Eclipse Periods were not practicable. The nominal 925-Joule discharges shown for 8th June and 15th July 2010, is that to maintain the CPU during 20 Minute Eclipse Periods.

Historical Battery Discharge Trend

- Battery Status as at 9th May 2010

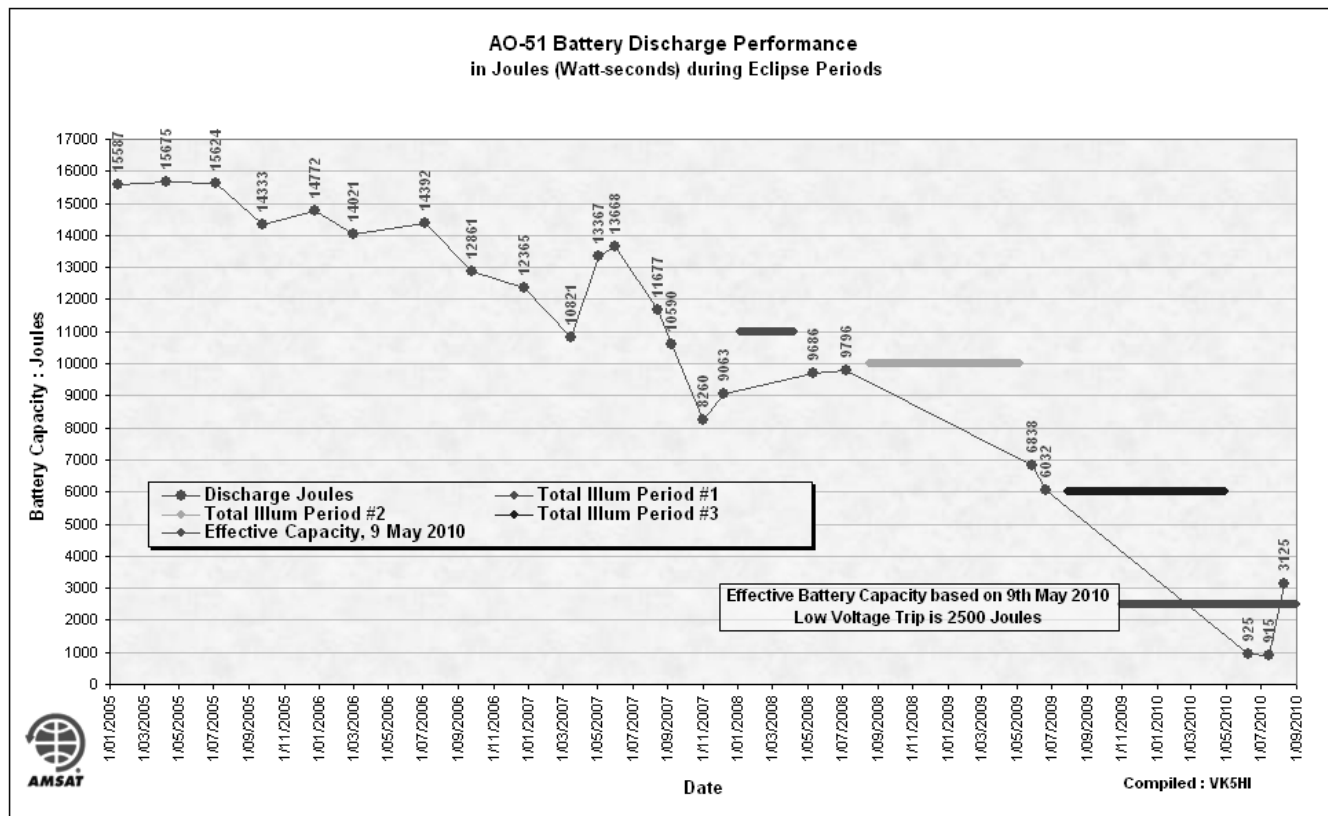


Figure 5

As stated previously it was fortuitous AO-51 encountered a low-voltage trip at 00:06 UTC on the 10th May 2010, which has allowed the calculation of a definitive Battery Capacity of 2500 Joules. This is shown in Figure 5. A Battery Capacity of 2500 Joules is totally inadequate to run a transmitter during an extended eclipse period. 2500 Joules is 12% of the Battery Capacity as at 16th January 2005.

A learned member of Amsat-NA expressed an opinion, some time ago, that he believed the batteries may recover when lower temperatures were experienced, once out of the total illumination periods. Due to a software anomaly on the 11th August 2010, with the Power Management System, AO-51 operated at low power (420 milliwatts) during the eclipse periods on that day, without a low voltage trip. This event allowed another definitive calculation of the Battery Capacity, with a result of 3125 Joules. This suggests an improvement from 2500 Joules on the 10th May to at least 3125 Joules, which is a 25% improvement. In real terms this is not a huge increase in capacity, but was sufficient to allow AO-51 to navigate the shorter eclipse period.

Historical Battery Discharge Trend

- Discharge Trend Prediction

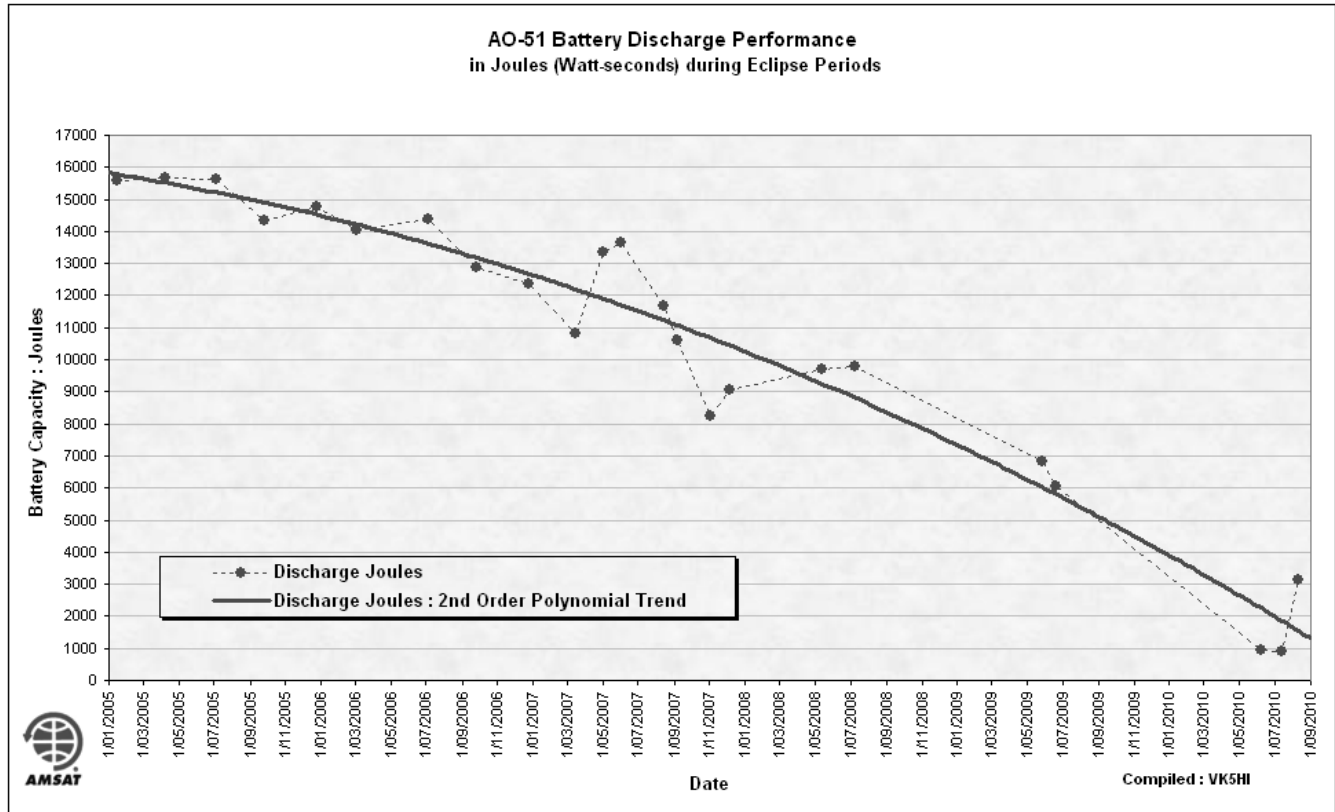


Figure 6

In Figure 6 shows the degradation of the batteries has followed a second order polynomial trend.

Total Illumination Period #4 commenced on the 24th August 2010. The cessation of that period will be on the 31st December 2010.

Clarification

It is not the intention of the authors to advance any substantive theory as to why the Battery Capacity has degraded to the current low levels, apart to note that heat may have been one of the contributing factors.

We have not advanced any discussion on the Charging Capacity of the Batteries, because of the BCR issue mentioned previously. Although work has been carried out on Charging Capacity the results are somewhat ambiguous and would not contribute positively to this presentation.

Spin Trends

Period 25th July 2004 to 2nd December 2009

The Spin Period / Spin Rate has been of significant interest to the AO-51 Operations Group and Alan Biddle WA4SCA.

When AO-51 was launched in July 2004 the Spin Rate was nominally 2.5 RPM.

After approximately three and a half years the Spin Rate commenced to decrease viz: the Spin Period increased. Figure 6 highlights the Spin Period from the 25th July to 2nd December 2009.

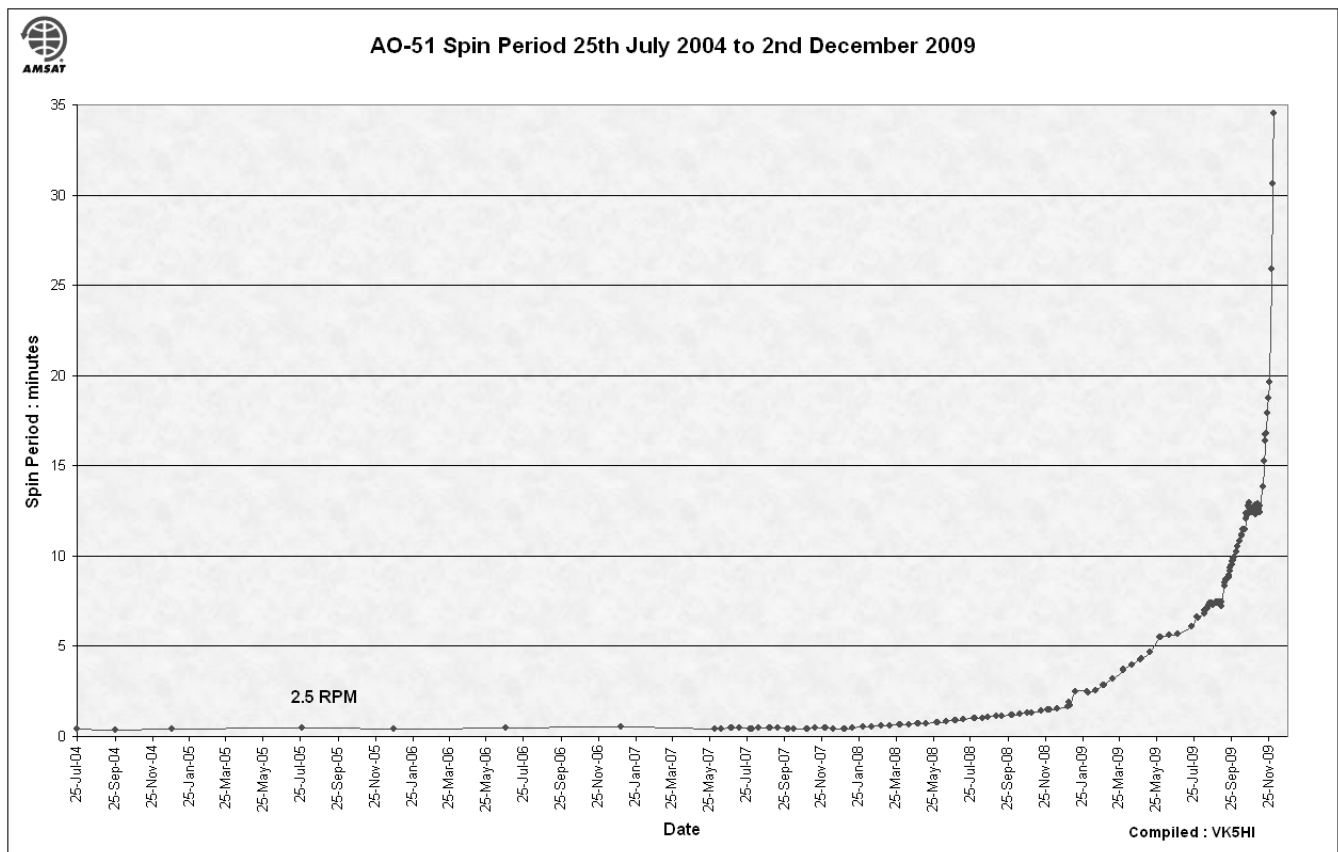


Figure 7

From Figure 7 the following observations can be made

- From July 2004 to January 2008 the Spin Period remained relatively constant at 0.4 minutes which equates to 2.5 RPM
- From January 2008 there is a gradual increase in the Spin Period.
- During 2009 the Spin Period escalated significantly. On the 2nd December 2009 the Rotation Speed of AO-51 was 0.03 RPM

When satellites are placed into orbit, they have a pre-determined level of spin to ensure that the designed thermal cooling of the satellite is maintained. Hence, the downside of the slowdown in AO-51's rotational speed is that the ability to maintain the designed cooling is diminished.

Spin Trends

1st December 2009 to 13th February 2010

The following Figure 8 identifies the Spin Period Profile following the FLIP Experiment.

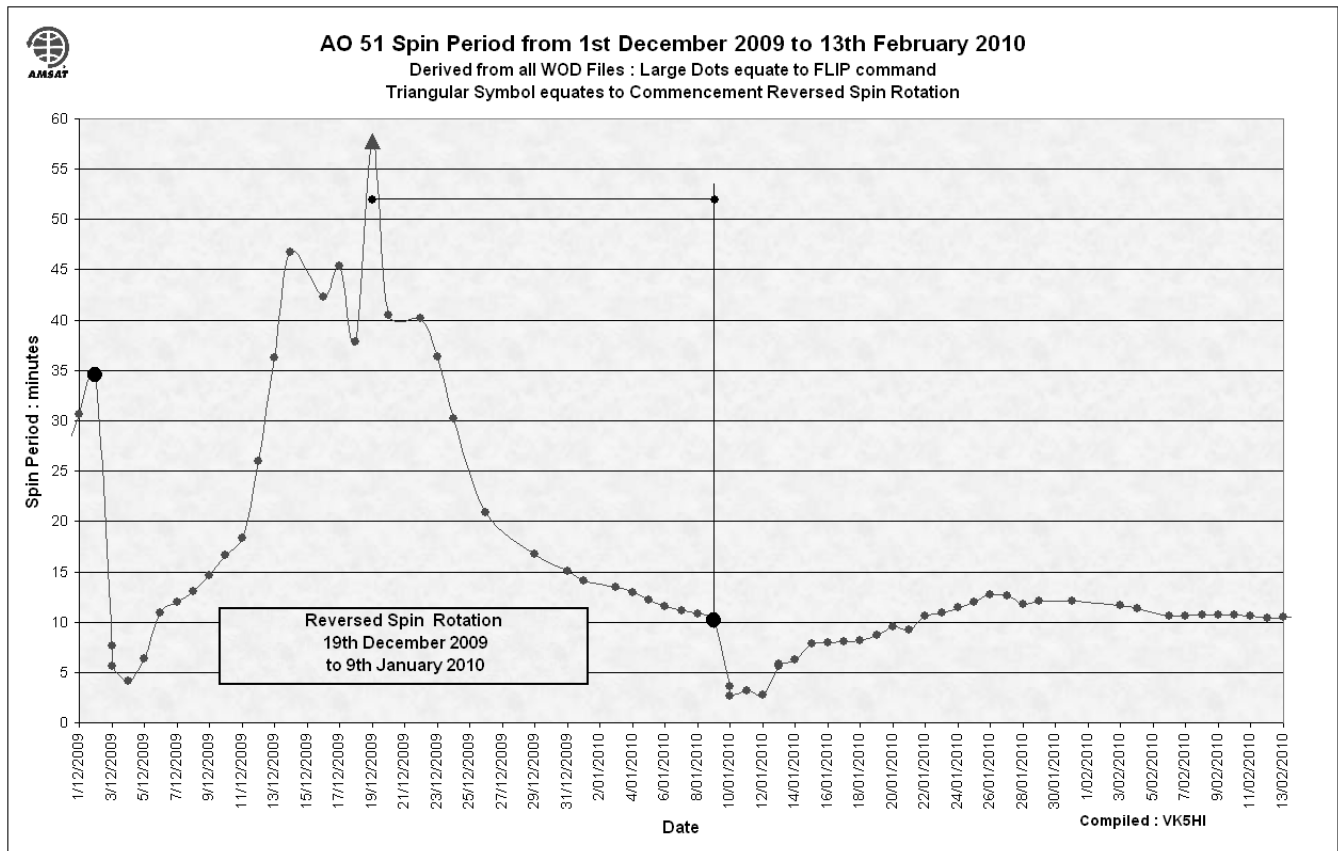


Figure 8

On the 2nd December 2009, AO-51 was commanded to FLIP, such that AO-51's Mode V and U antennae favoured the Southern Hemisphere.

Prior to the FLIP Experiment Tom Clark K3IO² mailed a note on the 2nd December 2009 to the AO-51 Operations Group that in part said.

"Since angular momentum must be conserved when you "flip" the s/c. The s/c body should precess (probably looking like tumbling) until the momentum dampers absorb the change. Keep an eye on the solar panel currents and I'll bet the spin rate will change".

Spin Trends

1st December 2009 to 13th February 2010

- From Figure 8 we can clearly observe that the Spin Period did indeed fluctuate. Following the FLIP command the Spin Period tended towards the launch value on the 4th December 2009.
- After the 4th December the Spin Period then continued to increase such that it peaked on the 19th December at 57.8 minutes and a Spin Reversal took place, such that AO-51 began spinning in the opposite direction, as confirmed by observations of solar panel current data.
- On the 9th January 2010 a second FLIP command was sent to AO-51 to revert back to its normal attitude. It was also recorded that AO-51 reverted back to its normal spin sequence.
- After the second FLIP command the Spin Rate reduced for a short period prior to “levelling” out.
- The spin reversal generated a significant level of interest. Alan WA4SCA drew the group’s attention, to documentation by Doug Sinclair¹, in which Doug discusses the issue of spin reversal. The reversible permanent magnet Torque Rod on AO-51 is very similar to that covered in Doug’s documentation.

Spin Trends

1st December 2009 to August 2010

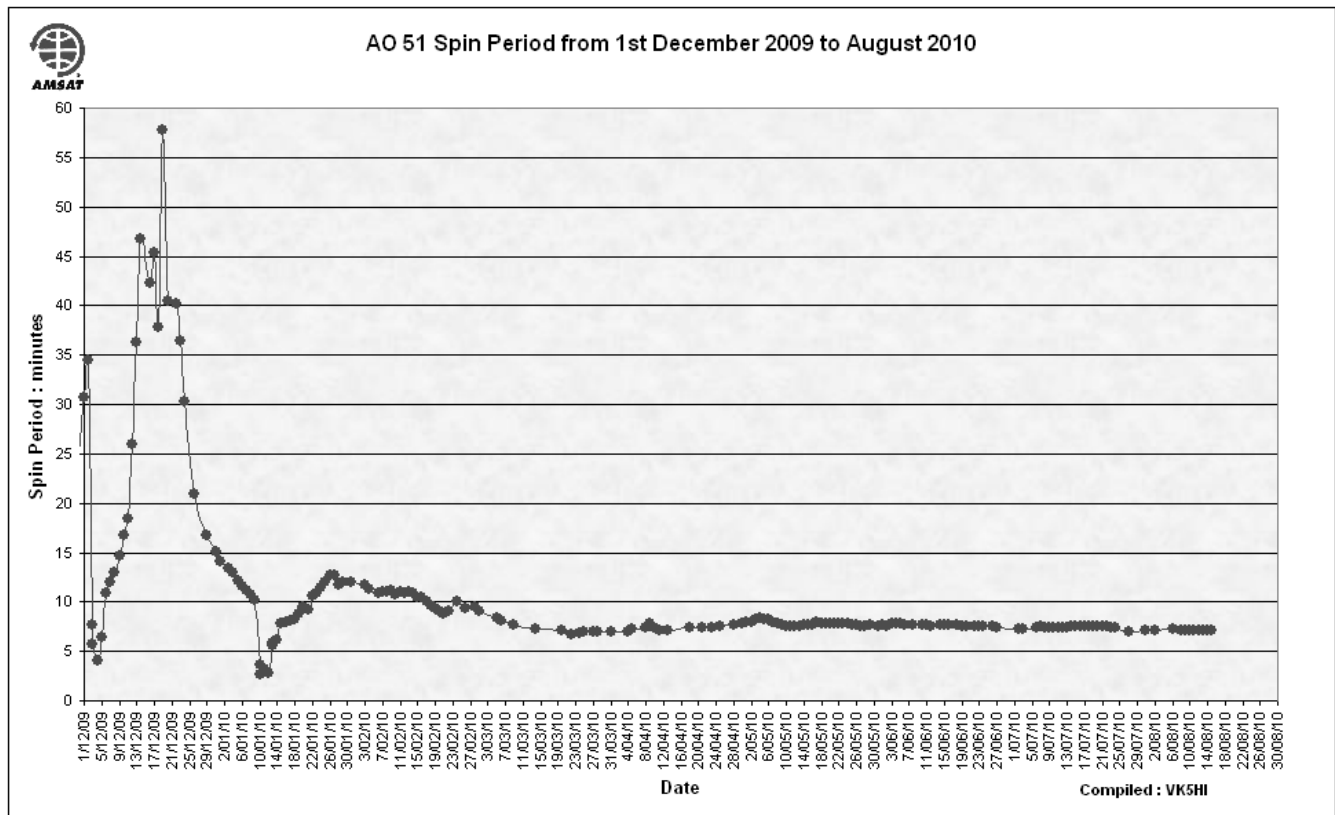


Figure 9

Figure 9 highlights that after some months from the second FLIP commands (issued to return the spacecraft's mode U and V antennae to again favour the Northern Hemisphere), AO-51 has stabilised at a nominal Spin Period of 7.5 minutes, which is a rotational speed of 0.13 RPM.

Prior to the FLIP commands Alan Biddle WA4SCA had also been monitoring the Spin Period for a considerable period of time. Alan mounted an excellent argument that perhaps the black and white Kapton tape used to maintain a spin component on AO-51, had deteriorated.

In Tom Clark's mail² previously quoted, he also made the following comments in respect to spin.

My guess is that the momentum loss is due to eddy currents induced in the s/c body by the earth's magnetic field. Sometime drop a piece of (non-magnetic) aluminum into the poles of a big magnet -- you'll see the aluminum change speed noticeably. Back in the antique days of mechanical speedometers in cars, the speedo cable turned a permanent magnet above an aluminum or brass disk connected to the indicator. As the magnet spun faster, eddy currents would drag the disk/pointer to higher values.

The stabilisation of the Spin Period since the FLIP experiment tends to suggest that the Kapton tape remains intact and that Tom's guess may have been correct.

Conclusions

This paper covers many hours of telemetry analysis and as such is just an overview of many observations. Follow-up can be made to either of the following.

Colin Hurst VK5HI	vk5hi(at)amsat.org
Mark Hammond N8MH	n8mh(at)amsat.org

Bibliography

1. Flight Results from a Novel Magnetic Actuator on the LatinSat Spacecraft
Doug Sinclair and Dr. Chris Damaren
<http://www.sinclairinterplanetary.com/publications>
2. Tom Clark: Email to AO-51 Operations Group 2nd December 2009.
3. AO-51 WOD Archive is obtainable from **ftp://ftp.amsat.org/amsat/telemetry/ao51/**

Appendix A: Calculation of Discharge Capacity

The Whole Orbit Data (WOD) from AO-51 is stored, then downloaded in a pre-defined format with a filename Wdmmddnn, where mm is Month, dd is Day and nn is filenumber. Software is available that converts these files to a Microsoft Office .csv file, for analysis.

Prior to a software change, (when more telemetered channels were added) the WOD's were labelled WEmmddnn. WOD's are generally of 5, 30 or 60 second sampling periods, however any sampling period can be programmed. Suffice to say the WOD's contain substantive performance information about AO-51.

The spreadsheet segment detailed below has been cut and pasted from the analysis of we070501, 5th July 2006. This WOD has been chosen as it has 60 second sampling and neatly fits on one page of this document.

By explanation Column 1 is the Time

The actual WOD voltages are such that they are the summation of Cells 1 to 6, Cells 1 to 5 etc. Columns 2 through 7 show the individual cell voltages, calculated from the telemetered WOD Values.

Column 8 shows the telemetered battery current. The section highlighted in **bold type** is the eclipse period being analysed.

Column 10 is the SUM of the individual cell voltages (columns 2 through 7) for the **eclipse period** i.e. when the Battery Current is negative.

We have defined Battery Capacity in Joules, where One Joule is One Watt-Second.

AO-51's bus structure being Direct Current (DC) allows us to use simple mathematics to calculate of Battery Capacity in Joules, from the WOD information.

$$\text{Joules} = \text{Watt-Seconds}$$

Battery Discharge Joules = Battery Voltage (multiply) Battery Discharge Current in milliamperes (divide) 1000 (multiply) Sampling Period in Seconds.

$$\text{Joules} = V \times I \text{ (ma)} / 1000 \times \text{Seconds.}$$

Column 10 shows the calculation of the Discharge Joules using the above formula for each sampling period of 60 seconds.

The value at the bottom of Column 10 (-14392.93) is the SUM of the discharge capacities. This is the value shown in Figure 5, for 5th July 2006.

The average Battery voltage at the bottom of Column 9 is a reference value used for a different analysis set.

Prepared by Colin Hurst VK5HI, 5th August 2010.

Extract from Microsoft Office Excel Spreadsheet

Echo Time	Cell 6	Cell 5	Cell 4	Cell 3	Cell 2	Cell 1	Battery I	Battery V	Joules
17:46:26	1.42	1.54	1.50	1.47	1.48	1.48	583.59		
17:47:26	1.41	1.54	1.49	1.47	1.48	1.47	328.00		
17:48:26	1.42	1.54	1.50	1.48	1.48	1.48	249.36		
17:49:26	1.43	1.54	1.50	1.48	1.49	1.48	591.45		
17:50:26	1.35	1.51	1.44	1.44	1.44	1.42	-917.77	8.60	-473.57
17:51:26	1.33	1.48	1.42	1.41	1.41	1.39	-953.27	8.44	-482.74
17:52:26	1.32	1.45	1.41	1.39	1.40	1.37	-972.99	8.34	-486.88
17:53:26	1.30	1.45	1.39	1.38	1.38	1.36	-984.82	8.26	-488.08
17:54:26	1.30	1.43	1.38	1.37	1.37	1.35	-988.77	8.20	-486.47
17:55:26	1.29	1.42	1.37	1.35	1.37	1.34	-988.77	8.14	-482.92
17:56:26	1.29	1.41	1.36	1.34	1.36	1.33	-992.71	8.09	-481.86
17:57:26	1.28	1.41	1.35	1.33	1.35	1.32	-992.71	8.04	-478.88
17:58:26	1.29	1.39	1.34	1.33	1.34	1.31	-996.66	8.00	-478.40
17:59:26	1.28	1.39	1.33	1.32	1.32	1.31	-996.66	7.95	-475.41
18:00:26	1.26	1.38	1.33	1.31	1.32	1.30	-996.66	7.90	-472.42
18:01:26	1.26	1.37	1.32	1.31	1.31	1.29	-996.66	7.86	-470.02
18:02:26	1.26	1.37	1.31	1.30	1.30	1.29	-996.66	7.83	-468.23
18:03:26	1.25	1.36	1.30	1.30	1.30	1.28	-996.66	7.79	-465.84
18:04:26	1.25	1.35	1.30	1.29	1.29	1.28	-1000.60	7.76	-465.88
18:05:26	1.24	1.35	1.30	1.28	1.29	1.27	-1000.60	7.73	-464.08
18:06:26	1.24	1.34	1.29	1.28	1.28	1.27	-1000.60	7.70	-462.28
18:07:26	1.24	1.33	1.28	1.28	1.28	1.26	-1000.60	7.67	-460.48
18:08:26	1.24	1.33	1.28	1.27	1.27	1.26	-996.66	7.65	-457.47
18:09:26	1.23	1.33	1.27	1.27	1.27	1.25	-1000.60	7.62	-457.47
18:10:26	1.23	1.32	1.27	1.26	1.26	1.25	-996.66	7.59	-453.88
18:11:26	1.23	1.31	1.27	1.26	1.26	1.24	-1000.60	7.57	-454.47
18:12:26	1.22	1.31	1.27	1.24	1.26	1.24	-996.66	7.54	-450.89
18:13:26	1.21	1.31	1.26	1.25	1.25	1.23	-1000.60	7.51	-450.87
18:14:26	1.21	1.31	1.25	1.24	1.25	1.23	-1000.60	7.49	-449.67
18:15:26	1.22	1.30	1.24	1.24	1.24	1.23	-1000.60	7.47	-448.47
18:16:26	1.20	1.30	1.24	1.23	1.24	1.22	-1000.60	7.43	-446.07
18:17:26	1.21	1.29	1.24	1.23	1.23	1.22	-1004.54	7.42	-447.22
18:18:26	1.21	1.28	1.24	1.22	1.23	1.21	-1004.54	7.39	-445.41
18:19:26	1.21	1.28	1.23	1.22	1.22	1.21	-1004.54	7.37	-444.21
18:20:26	1.20	1.28	1.22	1.21	1.22	1.21	-1004.54	7.34	-442.40
18:21:26	1.29	1.34	1.29	1.29	1.28	1.30	646.50	Avg Volts	Sum J
18:22:26	1.29	1.34	1.30	1.28	1.29	1.30	559.99	7.80	-14392.93
18:23:26	1.30	1.35	1.32	1.28	1.30	1.31	674.02		
18:24:26	1.30	1.35	1.31	1.29	1.29	1.30	434.17		
18:25:26	1.32	1.38	1.33	1.31	1.31	1.33	544.26		
18:26:26	1.32	1.38	1.34	1.31	1.32	1.33	697.62		
18:27:26	1.32	1.38	1.34	1.31	1.32	1.33	721.21		
1	2	3	4	5	6	7	8	9	10



NextGen CubeSat Proposal

Evolutionary Leveraging of Assets
and Opportunities

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



AMSAT needs to . . .

- Increase number of in-orbit spacecraft
- Leverage current design objects
- Creatively approach launch opportunities
- Increase educational outreach
- Maintain experimental edge
- Provide a stable technical program office

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



How to meet the needs . . .

- Engage University Participation
- Leverage Current Volunteers
- Maintain Evolutionary Design Principles

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



What is the NextGen Program

- A partnership between AMSAT, Universities and Industry to build the Next Generation of Amateur Radio ComSats
 - Binghamton University – State University of New York
 - IBM's Heritage Corridor Center for Advanced Studies
- Announced the NextGen Program @ October '09 AMSAT Symposium
- Display Engineering Model of first 3U NextGen ComSat @ Dayton in May '10
- NextGen Program Manager: Alex Harvilchuck, N3NP

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



NextGen Program Goals

- Evolutionary design using current assets
 - Insert new technologies to improve capabilities and reduce constraints
 - Provide launch-ready modules
- University outreach and teaming
 - Encourage the next generation of people
 - Partnership with information sharing
- Reduce cost and development schedule
 - Build reliable units for an affordable cost
 - Ability to quickly respond to launch opportunities

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



NextGen Program Goals

- Ability to offer complete assemblies @ low-to-no cost to other CubeSat University Teams – it allows them to focus on payload
 - AMSAT management of spacecraft during primary mission
 - When primary mission is over, the spacecraft is turned over to AMSAT for secondary mission – An Oscar in every CubeSat!
- Provides AMSAT a CubeSat Launch-on-Availability capability
 - Available, low-cost unit(s) with dedicated Oscar payloads on standby for rapid response to any launch opportunity

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



2009-2010 Accomplishments

- We have met the goals set out at AMSAT Symposium
 - Leveraged ARISSat-1 technologies to fit within 3U CubeSat frame
 - Rationalize Lessons Learned from ARISSat-1 and prior spacecraft to apply against NextGen
 - Display Engineering Model of NextGen @ Dayton in May 2010
 - 3U CubeSat Engineering Model from T6061 Aluminum
 - PseudoCapacitor-based proof-of-concept of the ARISSat-1 PSU
- Looking forward to the next phase of activity

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



2010-2011 Activity

- Leverage the good results
- Expand the effort to Six Teams.
 - Each is focusing on specific areas with achievable goals within the time constraints.
- Goal is to produce a modular, linear transponder communications pico-satellite for AMSAT and experimental use.
- Goal is to build major subsystems that will comprise AMSAT FOX
- The organizational effort would be reported on at the fall 2010 AMSAT Symposium, with the yearly report presented during the AMSAT Forum at the 2011 Dayton Hamvention.

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



2010-2011 Teams

- **Attitude Determination and Control (ADAC)**
 - Build/modify the appropriate sensor suite (Magnetometer, Cameras and Sun/Earth Sensors) to determine the spacecraft's attitude
 - Build/modify the appropriate mechanisms (Magnetorquer or Gyroscope or deployable tether) in order to manage the spacecraft's attitude for optimal power generation and communications operations.
- **Command and Data Handling (C&DH)**
 - Modify the command & control functions of the spacecraft to allow for greater functionality such as:
 - Improved control functionality (integrated physical configuration with more commands available) and Improved telemetry (spacecraft and experimental)
 - Improved capability to support new functions (upgraded PSU, RF Matrix, ADAC, etc.)
 - Rationalized experiment interface (scale to single experiment capability)
 - Modify ARISSat-1 deployment timer system to work with the CubeSat deployment switch specification

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



- **Power Generation and Distribution (PG&D)**
 - Refine a power supply board design with compact power distribution system
 - Develop methods for managing the power budget of the spacecraft
 - Develop an intelligent solar panel management system for the new PSU architecture
- **Antenna Systems Design/Development**
 - Develop/modify a reliable, deployable antenna systems for that fits within spacecraft budgets

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



2010-2011 Teams

- **Spacecraft Physical Structure and Thermal Model**
 - Continue the work on development of the spacecraft's physical bus structure and methods for managing the thermal, mass and volume budgets of the spacecraft.
 - Work with all other teams to integrate capabilities (antennas, solar panels, etc.) into the spacecraft bus.
- **Spacecraft Systems Integration**
 - Manage the four main budgets of the spacecraft (power, mass, volume and thermal)
 - Provide integration control of all aspects of the spacecraft (spacecraft bus and experiments).

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



2010-2011 Cycle Schedule

- Preliminary Design Review
 - Early December 2010
- Critical Design Review
 - Late January 2011
- Test Readiness Review
 - Mid March 2011
- Engineering Model Ready
 - Late April 2011
- Dayton Hamvention
 - May 2011

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



Participation

- Welcome participation by other Universities!
- Contact Program Manager for opportunities.
- Need AMSAT volunteer engineer(s) to work with each team

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)



For More Information

Contact:

Alex Harvilchuck, N3NP

NextGen Program Manager

e-mail: amsat@elkmtn.org

Contact: A. Harvilchuck, N3NP
(amsat@elkmtn.org)

B.U. Cubesat Power & Structure Team

MDP#07: NextGen CubeSat

Power & Structure Systems Final

*Michael Schneberg, CoE
Jason Ketcham, EE
Ryan Miceli, ME
Andy Mills, ME
Sidney Li, EE
Ian Moore, ME
Robert Stark, CoE*

*Sponsor: AMSAT
IA: Mr. Alex Harvilchuck
FA: Dr. Charles Westgate*

Binghamton University

1

Presentation Overview

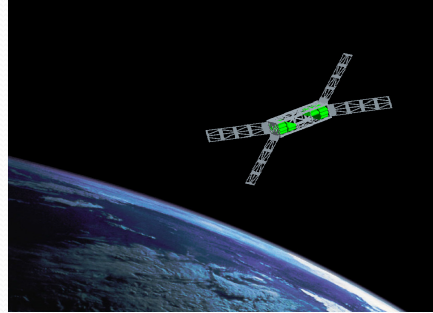
- Project Intro/Definition
- Analysis
- Final design
- Testing
- Schedule & Budget
- Recommendations & Summary

Binghamton University

2

Project Definition

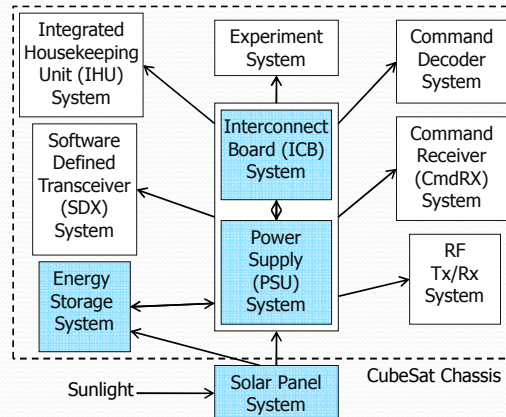
- Leverage current amateur radio satellite technology into a smaller 3U CubeSat frame.
- Increase the reliability, longevity and available power to the spacecraft.
- Increase satellite surface area to increase solar power collection.



AMSAT and CubeSat

- AMSAT – Radio Amateur Satellite Corporation has designed and launched small satellites since 1969 and provides access to the public
- Philosophy of low cost/high risk which is perfect for university projects and small scientific experiments
- CubeSat - A small satellite concept developed at Cal Poly that has a volume of 1 liter (10 cm on a side) (1U)
- AMSAT is currently working on ARISSat 1 and wish to modify ARISSat 1 technology into 3U CubeSat size

System Block Diagram



*Highlighted items indicate systems of redesign in NextGen CubeSat project

Presentation Overview

- Project Intro/Definition
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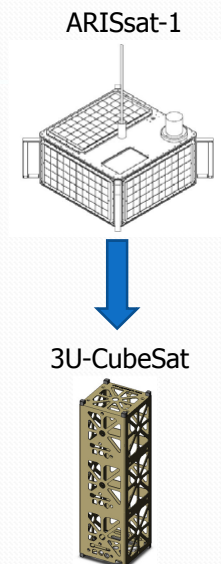
Electrical Systems Overview

- Requires a high power density and high energy density storage device
 - Li-Ion Battery
 - High Power Density
 - Low Lifetime
 - Electric Double Layer Capacitor (EDLC)
 - High Energy Density
 - Low Power Density
 - Near Infinite Lifetime
 - Pseudo Electric Double Layer Capacitor (PEDLC)
 - High Energy Density
 - Medium Power Density
 - High Lifetime

The main point of failure in many satellites is the **Battery System**

Mechanical Overview

- The 3U-CubeSat must execute many of the functions performed by ARISSat-1.
- Volume Comparison:
20 3U-CubeSat's = 1 ARISSat-1
- The emphasis of the project was placed on collecting optimum solar energy through the means of **solar panel deployment**.



Presentation Overview

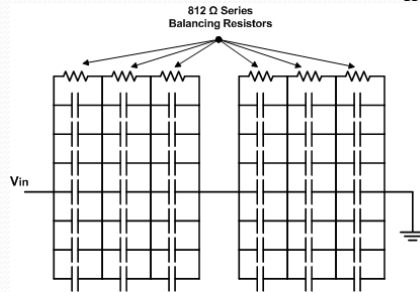
- Project Intro/Definition
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Capacitor Selection

- IOXUS 220F 2.3V Pseudo Capacitor
 - Local US manufacturing company located in Oneonta, NY
 - Chosen because of their long lifetime compared to batteries
 - Higher energy density than Electric Double Layer Capacitors
 - Slight lifetime decrease compared to EDLCs



Capacitor Array Design



- Configured as 6 series strings of 7 capacitors in parallel

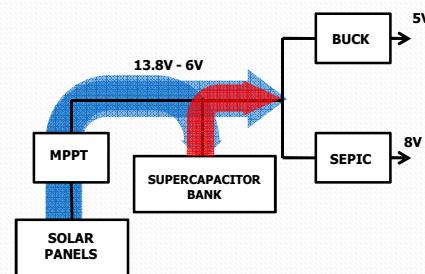
- Increased reliability by minimizing single point of failure
- Single failure only results in 1/42 energy loss
- Series balancing resistors allow for current path to prevent capacitors from overcharging
- Equivalent capacitance:

$$C_{eq} = 256.7F$$

$$E_{tot} = 24960 \text{ Joules}$$

NextGen CubeSat System Bus Design

- In contrast to battery powered satellite busses, which keep a constant voltage, the voltage on a Pseudo capacitor bus fades as the capacitors discharge
 - SEPIC and BUCK Regulators are needed to supply the Power Supply Unit (PSU) with the correct voltages
- Circuitry is designed to allow solar panels to simultaneously charge the capacitors and power the regulator circuits
 - This can allow the CubeSat to continue to function in case of a capacitor bank malfunction

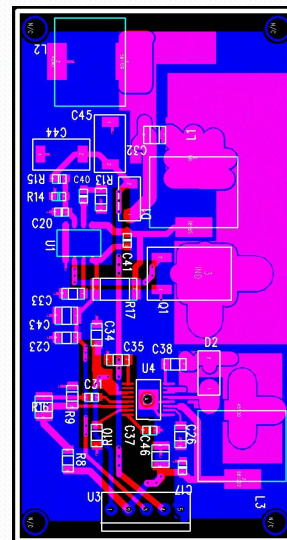


PCB Design

- This semester a PCB containing both regulators was designed and fabricated.
- The software used for this PCB was PCB-123
- The first step in this process was creating schematics of the two regulators.
- After creating schematics footprints for all necessary parts were created.

PCB Layout

- After building the schematics and footprints layout of the PCB began.
- Parts were placed in accordance with the suggestions provided in the datasheets.
- Size was kept as small as possible.

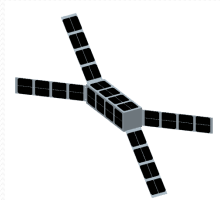


Satellite Structure & Power Collection

Assumptions:

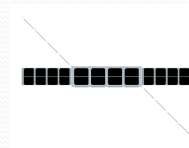
- Space Radiation AMo = 135.3 mW/cm^2
- Surface area per cell = 26.62 cm^2
- All angles of the deployed panels are at 45 degrees
- Solar Cell Efficiency is 28% (Ultra Triple Junction cells)

Best Case Orientation



33 Watts

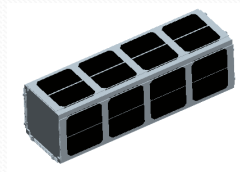
Worst Case Orientation



16.5 Watts

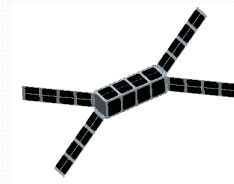
Solar Panel Deployment

Launch Conditions



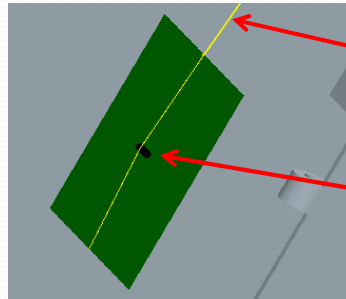
- Shape: $10 \text{ cm} \times 10 \text{ cm} \times 34 \text{ cm}$ (Required by Cap Poly Standards)
- Deployable panels are constrained by high performance polyethylene line.

Flight Conditions



- The lines are melted by the resistors
- Torsion springs deploy the panels into the final flight configuration

Mechanical Trigger



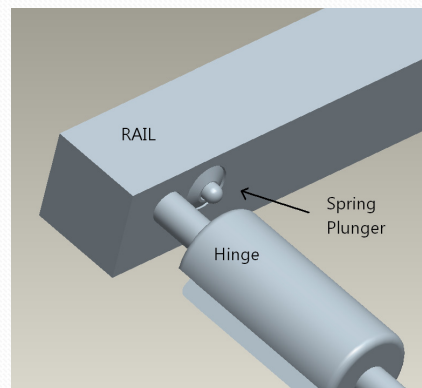
Dyneema[®] Line (.1mm)

Metal Film Resistor
(~75 Ohms)

- Dyneema[®] wire has a low melting temperature and is easily melted by the resistor.
- A similar design was successfully used in the Delft University Delfi-C3 CubeSat.

Locking Mechanism

- To lock the deployable panels into place will require the use of spring plungers to interfere the panel's rotation at the appropriate angle.



Mechanical System Demo

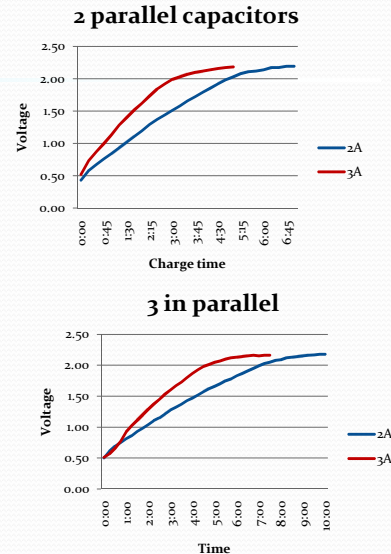
- NextGen CubeSat begins in launch configuration.
- A power supply begins to heat resistors.
- Polyethylene line breaks, converting the torsion springs potential energy to rotational motion.
- Deployable panels rotate and are locked into position by spring plungers.
- NextGen CubeSat is in the flight configuration and in optimal position for solar energy collection.

Presentation Overview

- Project Intro/Definition
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Capacitor Testing

- This semester all electrical and mechanical systems were tested.
- Electrical testing began with characterization of the super capacitors.
- Charge and discharge rates for these capacitors were measured.



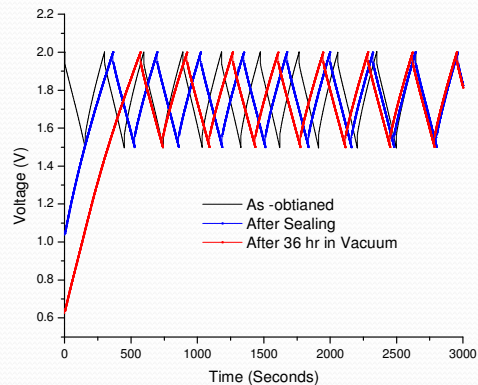
Vacuum and Temperature Testing

- After characterization additional tests were conducted.
- Before testing, the capacitors were sealed with Torr Seal[®] epoxy sealant
- The capacitors were put in a vacuum and their electrical characteristics were tested before and after.
- Next, the capacitors were heated from 20-65°C and then tested.
 - Freeze tests were not completed at this time due to lack of test equipment
- As shown in the graphs on the next page the capacitors retained all their electrical characteristics.
- Performed by Professor Rastogi and Stephen Cain

NOTE: Torr Seal[®] is a registered trademark

Vacuum Test Results

- As can be seen in figure, performed adequately with and without sealant
- Torr Seal® will be used to assure no leakage of contents due to the lack of pressure



PCB Testing

- All electrical components of the PCB were tested.
- Testing began by checking for shorts and any unwanted connections using a multimeter.
- Once connections were verified the PCB was tested under varying loads from 25% to 100% of the maximum load.
- The PCBs functioned as expected with an output voltage within 1% of the expected output.

Mechanical Testing

- Unit Testing
 - Machine parts measurement test
 - Resistor-polyethylene line test
 - Torsion Spring Rotation test
 - Locking Mechanism test
- Integration Testing
 - Deployment test
 - Space environment test

Presentation Overview

- Project Intro/Definition
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Schedule

- This semester's schedule included:
 - Prototyping of a Super Capacitor-based Energy Storage Device
 - Design and testing of a Capacitor-Based Power System
 - SEPIC and Buck converter integrated onto a PCB
 - Construction of a 3U CubeSat Mechanical Model

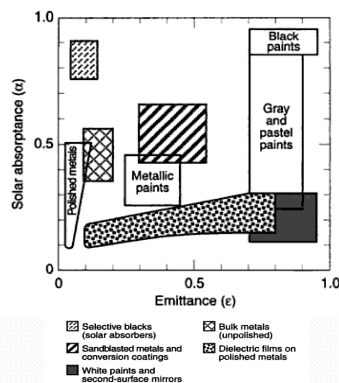
Budget

- \$200 worth of Pseudo Capacitors were purchased with a gift given to Binghamton University to further research into this new technology
- PCB prototype cost approx \$300
- Regulator prototyping cost approximately \$75 last semester
- ME design built by local with metal shop

Presentation Overview

- Project Intro/Definition
- Analysis
- Final design
- Testing
- Schedule & Budget
- Recommendations & Summary

Mechanical Future Recommendations



Source: David G. Gilmore, *Spacecraft Thermal Control Handbook*

- Perform thermal analysis to determine appropriate thermal finishes.
- Design appropriately sized communication antennas with deployment mechanisms.
- Determine the routing of wires and other connections between panel cells and internal components.
- Specify mounting of PCB's and other satellite components for proper thermal management.

Electrical Future Recommendations

- Modify Power Supply Unit (PSU) PCB design to incorporate design changes
- Merge the Inter Connect Board (ICB) PCB into the new PSU
- Include solar cell maximum power point control circuitry in proper configuration for a Pseudo Capacitor based design
- Implement relay design to shunt current to BUCK/SEPIC when capacitor bank is fully charged
 - Relay failsafe position would feed power to BUCK/SEPIC so spacecraft will continue to function

Summary

- Overall this project was a success.
- We completed a proof of concept design which includes the first ever use of super-capacitors in space.
- All EE and ME systems functioned as expected.
- We hope this project is continued next Year

Acknowledgements

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 - AMSAT and the AMSAT Board
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 - Jim Teed for Machining some of the parts
 - Dutchess Metal Supply Co.

Questions



AMSAT and ITAR: Lessons Learned

Barry A. Baines, WD4ASW

President-AMSAT

WD4ASW@amsat.org

Introduction

At the 2008 AMSAT Space Symposium, Bill Ress, N6GHZ presented a paper entitled “ITAR and AMSAT (And other export control rules)”ⁱ which provided an overview of US regulations pertaining to ITAR (International Traffic and Arms Regulations) administered by the Directorate of Defense Trade Controls (DDTC) of the US Department of State; EAR (Export Administration Regulations) administered by the US Department of Commerce, and a discussion of the necessity to determine whether or not it is possible for AMSAT to continue its long tradition of technical exchange and cooperative satellite development work with other AMSAT organizations. Bill’s overview was both timely and instructive, because the AMSAT BOD had been struggling to come up with a ‘workable approach’ that would allow AMSAT to continue to cooperate with AMSAT-DL and AMSAT-UK on Phase 3-E while abiding by the current law. Bill’s overview was very instructive for a number of people (including AMSAT BOD members) and highlighted the fact that AMSAT had to deal with this critical issue.

This paper provides a recap of the actions taken by AMSAT to deal with the challenges of ITAR since publication of Bill’s paper, provides some insight into the strategies developed by AMSAT as events unfolded over the past two years, discusses the overall impact of ITAR on AMSAT and lessons learned from the this process.

Background

Congress passed legislation in 1999 to transfer jurisdiction over commercial satellites from the Commerce Department to the Department of State as an ITAR-controlled technology in response to several high profile incidents where space technology had been unlawfully transferred to other countries. Successful prosecution of serious ITAR violations could result in significant monetary fines, loss of export privileges, loss of access to government procurement or government clearances and, in cases of willful violations, jail time.

Note that ‘export’ of space technology means not only the shipment of articles overseas. A ‘deemed export’ is the release of technical information to foreign nationals and can occur in a number of ways, including e-mail exchanges, conversations, exchanges of computer files, etc. and can take place within the confines of the United States or anywhere else. Given that AMSAT satellite builders were freely exchanging technical information with foreign nationals in

conjunction with the construction of AMSAT-DL's Phase 3-E satellite, in 2006 our volunteers were now wondering whether such exchanges were appropriate under the law. Consequently, AMSAT volunteers stopped their volunteer work on Phase 3-E in response to heightened concerns that perhaps AMSAT volunteers may have been violating ITAR.

In the Fall of 2006, AMSAT President Rick Hambly, W2GPS had been working with a law firm in the DC area to see if they could assist us in developing an appropriate management policy on ITAR compliance as well as determine an appropriate strategy for approaching DDTC on developing a Technical Assistance Agreement (TAA) that would pass DDTC scrutiny and be acceptable to other AMSAT organizations as signatories. This process was stymied by the fact that the attorneys that Rick was working with changed law firms in Spring 2007, and that transition eliminated their previous firm's interest in helping AMSAT and prevented them from continuing their work with AMSAT given the priorities of their new firm.

In Fall 2007, Rick then turned to a lawyer who was an AMSAT member and who had expressed interest in dealing with the ITAR situation. This individual spent considerable time getting up to speed on the myriad of details pertaining to this area of law and developed an initial set of recommendations as to how AMSAT might proceed. He drafted a TAA based upon requirements stipulated on the DDTC website and this draft was subsequently forwarded to AMSAT-DL and AMSAT-UK for their review/comment. This person became discouraged, however, when it became apparent in early 2008 that neither AMSAT-DL nor AMSAT-UK were interested in signing a Technical Assistance Agreement (TAA) because the language that DDTC requires in a TAA was unacceptable to the both AMSAT organizations. In particular, such language places foreign nationals under US Law (e.g. they could be prosecuted by the US government in the event items under the TAA are disclosed to foreign nationals that are not part of the TAA) and there were concerns that AMSAT organizations, being all volunteer, did not have the power to control the behavior of volunteers. Our intrepid volunteer lawyer, realizing that the ITAR issue was even more of a 'challenge' than when he started down this path, decided to bow out of the project.

By September 2008, it was becoming apparent that a new strategy was needed to deal with ITAR. Concerns about ITAR had caused several individuals to withdraw their volunteer support for AMSAT-NA. Morale within AMSAT Engineering was adversely impacted about concerns regarding past activities. Bill's paper in the 2008 Proceedings was the first overview of ITAR given to the AMSAT membership and marked the start of a new initiative to 'come to grips with ITAR'.

A New Approach

Prior to the AMSAT BOD meeting in October 2008 and while Bill was writing his Proceedings paper (I had seen and commented on his draft), I was advised that one of our AMSAT members had been involved with an ITAR issue in relation to his professional dealings. This AMSAT member had retained a lawyer whose specialty is ITAR and export rules because he and the firm in the United Kingdom that he was planning to do business with came to the realization that a Technical Assistance Agreement was needed and perhaps some of his past interactions with foreign nationals in conjunction with his business activities required an attorney to review his past activities. He also alerted some of the AMSAT satellite builders of his ITAR situation; this, and the growing realization of the seriousness of ITAR rules and their possible application to AMSAT, caused them to stop work on Phase 3-E due to concerns that the Phase 3-E project might have ITAR repercussions.

While the process of dealing with ITAR had been somewhat painful, the end result was that this AMSAT member was not fined and he was subsequently able to develop a Technical Assistance Agreement (TAA) that met DDTC requirements that would allow him to have a commercial relationship with a corporation in the United Kingdom. He was more than willing to share his ITAR experiences with me and provided valuable insight into the path he took in dealing with the problem. He also recommended his lawyer. The key takeaway that I received from him was “AMSAT needs to come clean with The Man”, meaning DDTC.

Up until this point in time, AMSAT was looking ‘forward’ in terms of dealing with the current regulatory environment. ‘Coming Clean’ meant informing DDTC of prior AMSAT actions that MIGHT have been ITAR violations but which no one really wanted to discuss for fear that there were indeed violations and then having to deal with the implications of such revelations. In essence, AMSAT and our corps of satellite builders were in fear of our past volunteer activities.

At the October 2008 AMSAT BOD meeting following my election as President by the Board, I outlined the basics of the conversation that I previously had with the AMSAT member and the Board agreed that I should initiate a conversation with the attorney that he had recommended to me, Frank Schuchat of Denver, CO. Frank is a founding member of the law firm Schuchat, Herzog & Brenman, LLC whose specialties include international trade law and federal regulatory matters. His prior experience in Washington, DC as an attorney with the US International Trade Commission (1983-1985) and service as a member of the President’s Export Council, Subcommittee on Export Administration (“PECSEA”) which advises the US Commerce Department’s Bureau of Industry and Security on federal export control and defense industrial base programs (1997-present) are but two examples of Frank’s extensive background with dealing with international trade. Mr. Schuchat’s professional biography may be found here:

http://www.shblegal.com/fra_info.php

I called Mr. Schuchat on November 6, 2008 upon my return to New England from my extended trip to Atlanta (the site of the Symposium) and subsequent time spent in the Southeast. During our initial conversation, we covered several areas:

1. Self-disclosure regarding past AMSAT activities involving international relationships;
2. Approaching Department of State (DDTC) about an ITAR exemption for IHU-3 and perhaps other components as well; and
3. The need to look to the future and ensure that AMSAT is properly positioned to deal with ITAR and that our volunteers are aware of governmental requirements. This not only means the appropriate documentation and training, but also recognizing that we have upcoming projects that must be addressed with respect to ITAR, such as SuitSat-2.ⁱⁱ

It was clear that AMSAT needed assistance with developing an appropriate strategy for dealing with these issues as well as guidance in terms of who within the State Department should be approached as well as how they should be approached. In other words, AMSAT needed a 'coach' on how best to deal with the DDTC to ensure that both AMSAT as a corporation and our volunteers as individuals would benefit from the 'voluntary self-disclosure' process and establish a dialog with DDTC on AMSAT's activities and desire to continue international technical exchanges in such a way as to abide by US Law as well as do so in an way that AMSAT could properly administer our international exchanges under ITAR.

Voluntary Self-Disclosure

A key strategy change was the realization that before AMSAT could have a direct conversation with DDTC about AMSAT's technical exchanges with other AMSAT organizations, AMSAT would first have to first disclose to DDTC what our previous experiences were with these organizations. If such interaction may have been violations of ITAR, then it would be best to follow a DDTC standard process known as 'voluntary self-disclosure.' By having AMSAT inform the DDTC of past activities, it would offer a number of benefits:

1. Organizations and individuals who self report themselves regarding potential ITAR violations are much more likely to be given an 'admonishment' rather than suffer legal penalties (e.g. fines/penalties or confinement).
2. AMSAT would provide details on ALL recent activity, such as Phase 3-E, with the aim of better understanding the nature of whatever violations may have occurred as well as ensure that we would not be later accused of not

being thorough in the revelation of past activities. However, given that there is a 5-year statute of limitations, AMSAT would not need to disclose details of actions taken with Phase 3-D/AO-40 or AMSAT's involvement as a consultant to the University of Toronto MOST satellite since those activities took place prior to 2003.

3. Once self-disclosure was made, AMSAT was then free to discuss not only past activities with DDTC, but discuss with DDTC future potential interactions with other AMSAT organizations as well.

"Voluntary self-disclosure" is a process where the applicant notifies the DDTC of past activities that may have been ITAR violations. The aim is to inform DDTC of activities before DDTC learns of potential violations themselves. The DDTC encourages voluntary self-disclosure as a means to encourage organizations and individuals to come forward with information that might be of value to DDTC, educate the applicant on whether the disclosed activities were indeed ITAR violations, and encourage future compliance with ITAR. Typically, but not always, the voluntary self-disclosure process results in an admonition only with the clear understanding that future violations of ITAR will not be tolerated. Violations that DDTC learns on their own are much more serious since fines or other punishments can easily be the end result.

Voluntary self-disclosure could only be done only ONCE and the expectation was that ALL potential violations would be self-reported. In other words, if there was any doubt as to the appropriateness of a past action, AMSAT should report it and let DDTC determine if indeed a violation occurred. If DDTC accepted the report, AMSAT could not 'self-report' again in the future and expect leniency from DDTC.

Over the next month I worked with Mr. Schuchat to ensure that he was thoroughly briefed on all AMSAT activities involving foreign nationals. The focus was on actions taken by US citizens under AMSAT 'sponsorship' in conjunction with the AMSAT-DL Phase 3-E Project and centered on four areas:

1. Can-Do! Bus
2. Internal Housekeeping Unit (IHU-3)
3. Software Defined Transponder (SDX)
4. Phase 3-E Mechanical and Thermal Design

I provided Mr. Schuchat with a variety of documents pertaining to the involvement of AMSAT-NA's volunteers in the Phase 3-E project, including:

1. Copies of scanned articles from the AMSAT Journal
2. Copies of scanned papers from AMSAT Symposium Proceedings
3. AMSAT News Service (ANS) articles on US participation in Phase 3-E
4. A list of 21 AMSAT volunteers who interacted with foreign nationals on satellite-related projects, including MOST, Phase 3-D and Phase 3-E

5. A list of materials provided by US Nationals to foreign nationals in conjunction with Phase 3-E.

From the materials that I provided, in early December Mr. Schuchat came to the conclusion that AMSAT should indeed follow the voluntary self-disclosure process as there was justification for requesting such a process from DDTC. Over the holiday season, he and I worked on the notification letter to be sent to DDTC as well as crafting an e-mail to be sent to the AMSAT volunteers involved with these satellite projects. On January 12, 2009, Mr. Schuchat sent a letter to DDTC signed by him and I notifying DDTC of AMSAT's intent to follow the voluntary self-disclosure process and with the commitment that such the report would be submitted to the DDTC within 60 days.ⁱⁱⁱ DDTC confirmed receipt of our letter on January 15, 2009.^{iv}

In an e-mail sent on January 27, 2009 to the AMSAT volunteers potentially impacted by the voluntary self-disclosure process, I noted the following:

My expectation is that the process that we are pursuing under Mr. Schuchat's guidance will benefit AMSAT and our volunteer satellite builders in a number of ways:

- It provides a well-structured approach for dealing with ITAR based upon sound advice/guidance from a recognized authority on ITAR.

- AMSAT will have direct communication with the State Department with appropriate counsel in the room to help guide the conversation and ensure that our concerns are appropriately conveyed.

- We will have an advocate in Mr. Schuchat that understands both the needs of the State Department and AMSAT who can help create an appropriate evaluation of how a small, volunteer organization such as AMSAT should be treated in a regulatory environment that is aimed primarily at corporate structures.

- By submitting a voluntary disclosure, AMSAT can 'clear the past' and lift whatever 'fears' or concerns that our volunteers and leadership may have about past activities.

- The burden of dealing with the 'uncertainties' pertaining to ITAR compliance will be lifted from the shoulders of our volunteers as well as the AMSAT leadership.

- AMSAT can move forward with a clearer understanding of its role and obligations under ITAR.

- Submission and acceptance of an exemption request will hopefully result in a cleaner process for working with other AMSAT organizations on specific

technical issues.^v

A conference call was held on February 3, 2009 that included AMSAT's legal team, members of the AMSAT Board of Directors (BOD), AMSAT senior officers, and the 21 US Nationals who were the satellite builders that were previously identified as having interaction with foreign nationals. The purpose of the call was to introduce the legal team (Frank Schuchat and Timothy Pitner) to the AMSAT participants, answer questions concerning the voluntary self-disclosure process, brief participants on next steps, and address any questions or concerns that individuals may have about the process. Subsequent to that conference call, interviews were scheduled between Mr. Schuchat's legal team and ten individuals involved with Phase 3-E technical discussions with foreign nationals to gather the facts that would be submitted to the DDTC by the March 15, 2009 deadline. This interview process took nearly a month and included conversations with foreign nationals who were involved with Phase 3-E.

The report itself was submitted to the State Department on March 12, 2009, three days prior to deadline^{vi}. It included not only information gathered during the interview process, but documents gathered from a variety of sources, such as the AMSAT Journal, AMSAT Proceedings, "AMSAT News Service" (ANS), AMSAT internal documents, and AMSAT publications. There were a total of 24 exhibits included in the submission:

- "2006 AMSAT Annual Report"
- Reprint of a NASA webpage "Ham Radio: What is AMSAT?"
- Copies of various correspondence pertaining to AMSAT's registration with the State Department "as a manufacturer and exporter of defense services and hardware/technical data"
- A letter from AMSAT-DL President Peter Guezlow to Frank Schuchat regarding support provided by AMSAT-NA for AMSAT-DL's P3-E satellite project
- Copy of Dick Jansson's "Phase III Spacecraft Thermal Design" from the November/December 1984 issue of 'Orbit' (Predecessor to the AMSAT JOURNAL)
- Copy of "AMSAT IHU-3: Update and Status" published in the 2005 AMSAT Symposium Proceedings
- Copy of "Doing More with Fewer Wires in the Harness: A New Approach to Spacecraft On-Board Command and Telemetry Interfacing" by Bdale Garbee, Chuck Green, Lyle Johnson and Stephen Moraco in the November/December 2003 issue of AMSAT Journal
- Copy of "P3E's Software Defined Transponder" by Howard Long that appeared in the 2008 AMSAT Symposium Proceedings
- Copy of "Additional P3E News" by Peter Gulzow that appeared in the March/April 2004 issue of AMSAT Journal
- Copy of "P3E-Status" by Peter Gulzow that appeared in the July/August 2004 issue of AMSAT Journal

- Copy of "AMSAT P3E Meeting Report" by Rick Hambly and Bob McGwier that appeared in the January/February 2005 issue of AMSAT Journal
- Copy of "IHU3 Meeting" by Peter Gulzow that appeared in the May/June 2005 issue of AMSAT Journal
- Copy of "Engineering Notebook II" by Bob McGwier that appeared in the July/August 2006 issue of AMSAT Journal
- Copy of Robert Bosch GmbH webpage: "What is CAN?"
- Copy of a paper, "Atmel Microcontrollers for Controller Area Network (CAN)" by Michael Passemard, Industrial Control Business Director of Atmel Corp. (<http://www.atmel.com>)
- Copy of "AMSAT Phase 3 Express: Eight Months After the Kickoff" by Frank Sperber that appeared in the January/February 2004 issue of AMSAT Journal
- Copy of "Software Defined Transponders, Future AMSAT Missions: Phase 3E and Eagle" by Tom Clark and Bob McGwier that was published in the 2006 Southeast VHF Conference Proceedings
- Copy of "ITAR and AMSAT (And other export control rules)" by Bill Ress that was published in the 2008 AMSAT Symposium Proceedings
- Copy of "Radio Amateur Satellite Corporation (AMSAT) Balance Sheet as of January 31, 2009", "Profit and Loss by Job January 2009" and "Profit and Loss Previous Year Comparison, January 2009"

Through the cooperation extended by our satellite builders and the paper trail review that various AMSAT officers performed, we ended up with a thorough and detailed submission to the DDTC that provided detailed information on AMSAT, our involvement with P3-E, an overview of the technology that was in question, an overview of the 'open source' approach to sharing this information, and a review of AMSAT's history of working on international satellite projects.

DDTC reviewed our submission and the Chief, Enforcement Division replied on March 24, 2009 with a single page letter received on April 3, 2009 by Mr. Schuchat that included the following:

We reviewed your disclosure and have determined that violations under the International Traffic in Arms Regulations (ITAR) did occur. The Department views these violations seriously and strongly cautions AMSAT to take necessary and immediate actions to strengthen its compliance process and procedures.

We note at this time that we are closing this case without taking action to impose a civil penalty. However, we may reopen the case if it is later determined that the circumstances warrant the initiation of administrative proceedings in accordance with Part 128 of the ITAR. We highly recommend your continued oversight and attention to prevent similar incidents from occurring in the future.^{vii}

This letter gave AMSAT three critical pieces of information:

- a. The level of detail provided was sufficient for DDTC to come to a conclusion and no further information was requested from AMSAT;
- b. AMSAT did indeed violate ITAR; and
- c. Our volunteers and the organization wouldn't be prosecuted for the actions that were documented in our voluntary self-disclosure.

As I noted in an e-mail sent on April 5, 2009 to those volunteers who were interviewed for the voluntary self-disclosure, "This is GREAT NEWS for AMSAT. It means that our thorough disclosure process has cleared us of any past 'wrongs' and that AMSAT can now focus on being forward looking rather than continuing to reflect on past actions."^{viii}

We also now realized that ITAR violations did indeed occur. However, we were now uncertain as to which of our many documented actions were considered violations or if all of our documented actions were indeed considered violations. For example, was publication of articles in the AMSAT Journal pertaining to US-developed technical items for Phase 3-E considered a violation, or was this considered 'public domain' since these were articles in a publication available to anyone who joined AMSAT? Given the way the DDTC letter was written, we were not certain. Consequently, without further clarification, AMSAT was forced to continue to remain in abeyance concerning all activities associated with Phase 3-E.

This uncertainty continues today, 18 months after the letter was sent to AMSAT. Despite our requests to DDTC for clarification on what steps AMSAT took that were actually ITAR violations, we have not received any further clarification from DDTC.

Next Step: Commodity Jurisdiction Request ("CJ Request")

Immediately after we received DDTC's decision, the next phase of our ITAR strategy was initiated, where AMSAT would seek clarification from DDTC of what constitutes 'public domain' and consider whether AMSAT should submit a 'Commodity Jurisdiction Request' in order to shift technical items pertaining Phase 3-E from ITAR under the Department of State to the Export Administration Regulations (EAR) under the Department of Commerce. Such a shift would lift a significant burden on AMSAT, eliminate the need for a Technical Assistance Agreement with non-US nationals, and simplify the administration associated with technical discussions. While an export license would still be required to physically ship items subject to EAR overseas, the 'deemed export' component of ITAR would be removed from compliance. As noted earlier, a 'deemed export' is the release of technical information to foreign nationals and can occur a number of ways, including e-mail exchanges, conversations, exchanges of computer files, etc. and can take place within the confines of the United States or

anywhere else. Placement of Phase 3-E subsystems under EAR would mean that AMSAT volunteers could hold technical discussions with AMSAT-DL and AMSAT-UK volunteers prior to making such information public domain.

Prior to arranging for the actual meeting with DDTC, AMSAT submitted a series of questions to them in order to frame the meeting agenda. Those questions were addressed to the head of the space and technology office of the licensing division rather than the enforcement division, which was unwilling to meet with AMSAT. Our intent was to seek guidance on the prospects of a Commodity Jurisdiction Request being favorably considered. Our hope was that DDTC would recognize that some if not all, of our Phase 3-E technical work would be considered 'not a defense service' and thus not be subject to ITAR. The original request for a meeting was made on April 20, 2009.^{ix} Due to scheduling conflicts, Frank Schuchat and I finally met with State Department at DDTC offices in Washington on July 1, 2009. At that meeting we discussed the Commodity Jurisdiction process and we were encouraged to take the appropriate steps to apply for the Request.

As a result of this meeting, we decided to proceed with the CJ Request approach. In order to adhere to the CJ Request process, AMSAT submitted four separate CJ Requests, one for each Phase 3-E subsystem (Can-Do! Bus, SDX, IHU-3, Thermal/mechanical analysis) involving US citizens. The submissions were made on July 28, 2009 to the DDTC.^x The submissions included supporting documentation that highlighted information previously published by AMSAT, such as articles in the AMSAT Journal. The Can-Do! Bus request, for example, totaled 33 pages including exhibits. Can-Do! is a technology originally developed in Germany for the automotive industry but which AMSAT was applying to a spacecraft. Our CJ requests were based on the fact that "these items, which do not have military applications, are used only for scientific and educational purposes by a non-profit organization which follows open source principles and makes its innovations available in the public domain."

Once received by DDTC, our requests were reviewed by a number of governmental organizations, including NASA, Department of Commerce and the Department of Defense. The input that was provided by each consulted government organization to these four requests are unknown to AMSAT and no explanation or supporting documentation was provided by DDTC along with their official response. We received word on October 16, 2009 (a week after the 2009 Space Symposium @ BWI Sheraton) that all four CJ Requests were denied by the DDTC.^{xi} This clearly was disappointing news and meant that all four areas of Phase 3-E development remained subject to ITAR. Further, since no explanation was given for these decisions, no recognition was given to our publications, open source approach to development, and lack of commercial gain for the items involved.

Just as was the case with our voluntary self-disclosure, the DDTC provided no

details for the decisions that were rendered which would help to guide future conduct. Just as we had not received specific information on which of the actions taken by AMSAT and identified in our voluntary self-disclosure back in January were considered ITAR violations, we were once again dealing with a governmental response that provided no details as to why our four commodity jurisdiction requests were denied.

Consequently, AMSAT now faced the following situation:

- All of the subsystems development work done by US citizens in support of Phase 3-E is subject to ITAR;
- AMSAT's actions identified under our voluntary self-disclosure were deemed to be violations of ITAR, though details on specific actions that were deemed violations are not known;
- Continued efforts to maintain working relationships with AMSAT-DL and AMSAT-UK would require ITAR-based Technical Assistance Agreements; and
- Our position that the technical work being done was in the public domain following open source principles were not accepted by the DDTC.

Further, uncertainty regarding the applicability of 'Public Domain' remained. Under ITAR, technical material considered to be in the 'public domain' is not subject to ITAR. The question is, "How does technical information become public domain?"

Request for Advisory Opinion

Since the DDTC Office of Policy did not accept the positions taken in our four CJ Requests, further clarification was needed to better understand how AMSAT should consider use of public domain. During the month of November I worked with Mr. Schuchat to craft an 'Advisory Opinion' request to DDTC seeking clarification on what constitutes 'public domain'. On December 4, 2009, AMSAT went back to the DDTC seeking clarification on what constitutes 'public domain.' As noted in our Request for Advisory Opinion (AO), given that our systems were subject to ITAR and that the Technical Assistance Agreement (TAA) approach had serious problems given that foreign AMSAT organizations were very reluctant to sign such documents, we were seeking guidance from DDTC concerning "how it (AMSAT) may continue its cooperative activities with AMSAT-DL and other foreign "AMSAT" organizations while still assuring compliance with ITAR."

In our submission, AMSAT requested guidance in two areas:

1. Technical data and public domain issues.

AMSAT has consistently maintained a policy of treating any technical information generated through its volunteer projects as “open source” and publicly available; accordingly, AMSAT regularly disseminates information on technical activities in its journals and published proceedings, at presentations at conferences (where some foreign persons usually are in attendance) and through various means of electronic distribution. AMSAT members also organize their own personal communications on technical subjects among fellow members. It is an established and accepted tradition that technical information generated for AMSAT projects is not restricted or licensed for a proprietary purpose.

We request advice on the following specific points:

- Can AMSAT presume that AMSAT technical information (disseminated by the methods described above) is largely or exclusively in the public domain?
- Is information considered to be in the public domain if it is distributed electronically to a wide and unrestricted audience?
- How would AMSAT identify exceptions, if any, to the public domain rule?

2. Licensing of Defense Services.

AMSAT appreciates that the provision of ‘defense services’ to AMSAT-DL or other foreign amateur radio societies may require a license, independent of whether the related technical information is in the public domain or is considered “technical data.”

- Is the DSP-5, Application/License for Permanent Export of Unclassified Defense Articles and Related Unclassified Technical Data, an appropriate mechanism to obtain authorization for the export by AMSAT of any specific defense services and related defense technical data (i.e. any technical information that is not in the public domain)?^{xii}

The Directorate of Defense Trade Controls (DDTC) responded to our advisory opinion request on March 1, 2010. Specifically, as Mr. Timothy Pitner summarized State’s response, AMSAT was advised:

(1) Information distributed only via the Internet or other electronic means is not in the “public domain” within the meaning of ITAR; and

(2) While the regulatory framework favors the provision of defense services and technical data to be accomplished under a TAA or manufacturing license agreement, in “exceptional circumstances” typically where the scope and level of technology release is low, the State Department may issue a DSP-5 license authorizing the export of defense services.

The response from DDTC regarding public domain has several implications:

- a. If electronic means is not an acceptable method of making information

'public domain', then only published material is considered public domain. Consequently, free exchange of information electronically could only occur after publication that prevents free exchange during development of technical information. For example, two AMSAT members who are US nationals could publish an article in the AMSAT Journal and make it public domain, but they could not collaborate with a foreign national in the development of that article. It also likely means that publication could only take place in the United States since foreign nationals could not see the material prior to actual publication unless there was a TAA in place.

- b. "The only exception to the public domain rule would be if the export met one of the applicable ITAR exceptions or did not fall under the definition of technical data." ^{xiii}

The potential application for a DSP-5 license is one that AMSAT continues to consider, but no action has been taken. After nearly two years of dealing with the DDTC, we have learned that as a non-profit organization connecting widely dispersed volunteers with strong engineering and other skills who exchange ideas and collaborate on projects as a 'hobby', we are unlike any other 'exporter' in DDTCs world and the only response they seem to have available is to deny our request for guidance. Given the significant AMSAT resources, including legal fees, volunteer time (senior officer, BOD and others) expended to date on ITAR, we realize that further investment in this process may not result in a tangible benefit, as it is much too easy for DDTC to summarily deny our request, even if it's representatives acknowledge that such a path is 'reasonable'.

A decision by AMSAT to pursue a DSP-5 license in order provide a means for continued AMSAT involvement with Phase 3-E would be contingent upon several considerations:

-The cost of pursuing this approach. The legal fees would be based upon the number of man-hours required to develop the application and manage the process. At this point, we estimate fees in the range of about \$800-\$2,000.00.

-What are the expected benefits? Given that AMSAT volunteers withdrew from Phase 3-E development over four years ago, the technology has evolved and development work has been taken over by Europeans. For example, the FPGA originally used for the IHU-3 is no longer in production; AMSAT-DL is looking towards a different design. Given this evolutionary process, how critical is it for AMSAT volunteers who are US citizens to share technical information (schematics, PCB layouts, etc.) for what may be an 'obsolete' design?

-Are AMSAT volunteers willing to help with Phase 3-E? Given the hard lessons learned about ITAR compliance, it is easy to understand why US Nationals would prefer to be no longer involved with international projects.

-Would individuals (both US and foreign nationals) be willing to sign the DSP-5 application and subsequent end user certificates? Since neither AMSAT nor AMSAT-DL satellite builders are 'employees', volunteers would be responsible for their own actions and would be required to sign the DSP-5 documents as individuals. ^{xiv}

-What are the prospects for Phase 3-E? AMSAT-DL continues to look for funding to pay for final development and the launch costs for this satellite. At this point in time, there are no guarantees that such funding will be secured or that the satellite will be completed.

2010 AMSAT-UK Colloquim

I attended the AMSAT-UK Colloquium held in Surrey during the last weekend in July. I gave a presentation on AMSAT activities, including the extensive effort we had undertaken in response to ITAR-related concerns. My presentation was an 'eye opener' for many in attendance, for some were unaware of the severe limitations that ITAR places on US citizens regarding discussions and technical exchanges that fall under this law.

I reviewed the steps that had been taken since October 2008, including the implications created by our voluntary self-disclosure process, and made it clear that while AMSAT considers international cooperation on satellite projects to be a cornerstone of our organization, we could not assume the risk of violating ITAR. Given that neither ITAR nor the government bureaucracy was designed to easily deal with the idiosyncrasies of an all-volunteer not-for-profit organization that built small communications satellites, AMSAT was having significant issues in convincing Washington of the appropriateness of volunteer satellite builders openly sharing information that is considered subject to ITAR with like-minded satellite enthusiasts in Europe.

As AMSAT-UK videotaped all of the Colloquium presentations, my presentation may be found in the film archive at: <http://www.batc.tv/>.

Lessons Learned from the ITAR Process

The past two years have been very revealing, as AMSAT has dealt head on with 'coming to grips with ITAR.' While this was certainly a very necessary process, particularly with regard to resolving past activities and clearing the air for both our volunteers and the organization itself regarding AMSAT's involvement with Phase 3-E, our experience has also been a huge investment in AMSAT management talent and focus as well as a large financial outlay. AMSAT's legal fees related to ITAR have exceeded \$50,000.00 since October 2008. Here are my 'lessons learned' from this experience (not in any particular order):

1. You may think that AMSAT is primarily a scientific and educational organization, or even view AMSAT as an amateur radio organization, but the US Government defines AMSAT as a “Munitions Supplier.” That is because we build ‘communications satellites’, a category that is included in the US Munitions List. No exceptions are given to organizations based upon size of the organization, size of the satellite being built (cubesats qualify under the munitions list), type of satellite, or whether the person(s) involved are volunteer or paid.

This blanket definition has a financial impact on AMSAT as we pay a \$2,500 licensing fee each year to be registered with DDTC. This license allows AMSAT to apply for export license for such things as sending antennas to ESA for placement on the Columbus Module on the ISS (which occurred in 2009 as we were dealing with ITAR voluntary self-disclosure). AMSAT was prepared to submit an export license for Radioskaf-V (ARISSat-1) until NASA agreed to do the export licensing paperwork and ship the satellite to RSC-Energia rather than have AMSAT ship the satellite to Russia.

2. ITAR is for real. AMSAT has cleared itself with DDTC with voluntary self-disclosure, but we get only one ‘get out of jail free card’. Any future violations will cause real hardship for both the organization and the volunteer(s) who disobey the law.
3. ITAR has unintended consequences. Congress forced communications satellites into ITAR in 1999 without regard to the impact on not-for-profit, all volunteer organizations. The same rules apply to AMSAT as any large or small commercial entity in the communications satellite sector. Even the for-profit sector has problems with the current situation and industry associations have stepped up their efforts to persuade the government that communications satellites should be controlled by the Commerce Department because of the negative effect ITAR has on US exports in this area.
4. It is easier for a government organization to say “no” than to say “yes.” The decision not to allow Phase 3-E subsystems to shift from ITAR to EAR without giving us any supporting documentation or rationale reflects the ‘black box’-like regulatory process and the lack of a framework to address the needs of smaller scientific and educational organizations. DDTC processes as many as 80,000 license applications annually and is stretched for resources as it is. But our preference is DDTC should exercise some discretion to differentiate between organizations and projects under varying circumstances which do not implicate US national security and foreign policy interests.

5. It is very expensive to abide by the regulatory process. AMSAT has invested over \$50,000 in legal fees dealing with ITAR since 2008. We have received excellent legal advice for those funds and I have no qualms defending the decisions made that resulted in these expenditures. But there is a finite limit as to what AMSAT can afford to spend on trying to maintain international working relationships that had been in existence for over 20 years. The 'cost' of ITAR also includes the loss of 'advancing the state of the technical art' that is achieved through international cooperation and is the underlying basis for encouraging amateur radio in the first place.
6. Government activities under ITAR are designed to block information exchange, not encourage it. There is no incentive for a government employee to approve an exemption to ITAR when there exists the minutest chance that such a decision will be criticized at a later date.
7. A corollary is that it is currently difficult for government to differentiate between 'threat levels' and to focus on protecting information that is more critical than others. Even if a 'rogue nation' secured the IHU-3 design, clearly the value of this technology is significantly less critical than the control hardware/software of military hardware. Yet, DDTC has determined that even the IHU-3 requires 'protection' under ITAR and that it cannot be transferred to EAR. DDTC is not willing to differentiate between the technical developments done by volunteers in someone's garage 'on the cheap' and a multimillion dollar commercial or government contract.
8. Future AMSAT satellite projects will either be 'US only' (such as Project Fox) or fall under someone else's Technical Assistance Agreement, such as the agreement between NASA and RSC-Energia that is being applied to Radioskaf-V (ARISSat-1). Given that AMSAT's ability to work with Russian nationals is contingent upon this TAA, all communications between AMSAT and Russian nationals includes NASA personnel to ensure that the TAA is strictly adhered.
9. The impact of ITAR is worldwide within amateur radio. Along with the direct impact on AMSAT-DL's Phase 3-E project, ITAR also prevents US nationals with assisting other satellite programs as well, such as AMSAT-ZL's KiwiSat without first gaining the appropriate government approvals. The cost of supporting that project is not only the legal fees associated with developing a TAA (to be paid by 'someone') but the significant legal obligation that foreign nationals (who are also volunteers) must be willing to subject themselves to US law.
10. Government agencies don't know how to deal with 'unique groups' such

as AMSAT. While AMSAT prides itself with our distinguished history of literally building satellites in our garages, government sees AMSAT, an all-volunteer not-for-profit organization as a 'threat'. Commercial entities have paid employees and a hierarchical structure. Failure to abide by company rules and government regulations results in firing and loss of income for the offending employee. There are strong organizational incentives in a paid environment for compliance. Likewise, corporations are liable for the actions of their employees.

Volunteer organizations don't 'hire' or 'fire'. Volunteers decide what they will or won't do as volunteers. The only 'control' that a volunteer organization has over their volunteers is 'moral persuasion' and withholding reimbursement funds for expenses (such as paying for parts or travel). Such lack of control is seen as a significant 'downside' by regulators in dealing with enforcement since volunteers can act independently and organizations don't have direct control over volunteers.

Consequently, regulators may be more likely to hold individuals accountable, whereas in industry the organization is targeted for any fines and penalties. This direct involvement can have a chilling effect on volunteer participation in projects involving ITAR compliance since the individual may need to take steps to ensure that they are fully aware of the commitments being made as an individual and may even seek their own legal counsel prior to signing such documents.

11. Compliance with ITAR is both expensive and time consuming for AMSAT. The administrative cost of ITAR compliance even when there are no legal issues can be very costly. Failure to have the proper paperwork can result in legal action by the DDTC even if the 'spirit' of ITAR is fully complied. For example, within the scope of a TAA, logs must be kept of all interactions with foreign nationals involving subject matter applicable under ITAR as well as documentation of all exchanges. This includes phone calls, e-mail exchanges, visits to facilities, etc. There must also be a compliance program in place designed to ensure that all affected personnel are trained and familiarized with proper procedures under ITAR. If AMSAT were to have a TAA with another organization, part of the 'cost' of administration of that TAA would be compliance administration.^{xv}

An interesting legal question is whether an all-volunteer organization such as AMSAT can indeed be held accountable for ITAR compliance if the legal documents (TAA, DSP-5, etc.) are to be signed by individuals and not by AMSAT. Again, the legal structure behind ITAR doesn't necessarily fit well with an all-volunteer organization. Would individuals serving as AMSAT volunteers be held accountable for their own compliance training or would AMSAT?

Even if there isn't a formal relationship with other AMSAT organizations, satellite builders must be mindful that there are severe limitations with release of information subject to ITAR prior to that material becoming public domain.

12. While there is continuing talk in Washington about revising ITAR to make US companies more competitive in the international marketplace, there are no guarantees that such changes will relieve AMSAT or universities of the burdens of ITAR. We are below everyone's 'radar screen.' We don't fit 'the mold' of 'paid organizations' that are building satellites. Universities are also struggling with ITAR compliance as there are no 'public domain satellites' when special boards are added, such as experiments. In some cases, universities are excluding foreign nationals from satellite projects as a precaution, even though a significant percentage of their engineering students are foreign nationals.

In summary, the past two years have been stressful ones for AMSAT as we have dealt with ITAR and come to understand the roles and responsibilities under this law. Unfortunately, a cornerstone of AMSAT's relationships with other AMSAT organizations for the past 30 years (international satellite development for the benefit of amateur radio worldwide) is no longer encouraged under US law. This inability to cooperate openly on international projects without severe burdens placed on individuals and organizations is a significant loss for amateur radio, and in turn for US science and technology.

On a brighter note, AMSAT's legal obligations are now well-understood and our volunteers who were involved in prior international projects no longer worry about legal consequences of past actions. We are in position to look forward rather than be concerned about the past. Just as important, AMSAT has done its best to try to maintain some semblance of international cooperation in the midst of a regulatory environment that discourages such activity. Hopefully, the regulatory environment may evolve, but until legal conditions do indeed change, it looks as if AMSAT will be working on its own satellite projects without the cooperation of foreign nationals for the foreseeable future.

Footnotes

ⁱ Ress, Bill, N6GHZ “ITAR and AMSAT (And other export control rules)”, Proceedings of the AMSAT-NA 26th Space Symposium (Silver Spring, MD:AMSAT, 2008), 4-10.

ⁱⁱ Baines, Barry “ITAR.” E-Mail to Frank Schuchat. November 7, 2008.

ⁱⁱⁱ Schuchat, Frank “Voluntary Disclosure-AMSAT” Letter to DDTC, January 12, 2009

^{iv} Schuchat, Frank, “1/15/09 Letter from State Department”, E-Mail to Barry Baines. January 26, 2009 with attachment

^v Baines, Barry “AMSAT’s Plans for ITAR Compliance”, E-Mail to 19 Recipients. January 27, 2009 with attachment

^{vi} Schuchat, Frank “State Department Filing” E-Mail to Barry Baines, March 13, 2009

^{vii} Smith, Glen “DDTC Case No. 09-0000333”. Letter to Frank Schuchat. March 24, 2009

^{viii} Baines, Barry “State Department Response to AMSAT’s Voluntary Disclosure”. E-Mail to AMSAT BOD and others, April 5, 2009

^{ix} Schuchat, Frank “AMSAT—Compliance Follow-up to Disclosure” E-Mail to Anthony Dearth. April 20, 2009 with attachments

^x Pitner, Timothy “AMSAT Commodity Jurisdiction Requests” E-Mail to Barry Baines & Frank Schuchat. July 30, 2009 with attachments

^{xi} Schuchat, Frank “CJ Request”, E-Mail to Barry Baines. October 16, 2009 with attachment

^{xii} Schuchat, Frank “Request for Advisory Opinion—Registrant Code M-2175—DDTC Cases CJ442-09, 443-09, 444-09 and 445-09” Letter to Mr. Walt Rainey. December 4, 2009

^{xiii} Pitner, Timothy “State Dept’s Advisory Opinion” E-Mail to Barry Baines. March 1, 2010

^{xiv} Schuchat, Frank “Re: AMSAT” E-mail to Barry Baines. March 19, 2010.

”Individuals would have to sign an end-user certificate”

^{xv} Ress, “ITAR and AMSAT (and other export control rules),” 9. See this page for a brief overview of documentation and reporting rules regarding administration of TAAs.

Satellite and Earth Station Technology

Characteristics of simulated data multicasts transmitted over K3IO's proposed GEO-Eagle radio communications platform

Paul D. Wiedemeier, Ph.D., KE5LKY
Assistant Professor of Computer Science
The University of Louisiana at Monroe
Computer Science and Computer Information Systems Department
College of Business Administration
700 University Avenue, Monroe, Louisiana 71209
318-342-1856 (Work) or 318-396-1101 (Fax)
wiedemeier@ulm.edu, wiedemeierp@gmail.com, or KE5LKY@arrl.net

Amir R. Shrestha
The University of Louisiana at Monroe
Computer Science and Computer Information Systems Department
College of Business Administration
700 University Avenue, Monroe, Louisiana 71209

Abstract

At the 27th Annual ARRL and TAPR Digital Communication Conference, Dr. Tom Clark (K3IO) introduced a “straw man” proposal that mounts the AMSAT Eagle communication module on a future commercial geo-stationary Earth orbit satellite. Using information obtained from his presentation, we simulated data multicast transmissions over GEO-Eagle, which is Dr. Clark's name for this proposed “bird”. Our simulations show that file sizes less than or equal to 128 KB can be transmitted within two minutes, even at the periphery of the GEO-Eagle's footprint. We hope that the data generated by our research will benefit individuals within the amateur radio community who transmit data, specifically those who provide emergency data communication.

Key Words

Emergency Communication, Data, Multicast, Simulation, K3IO, GEO-Eagle, Geo-Stationary, Earth, Orbit, Satellite, Ns-2, Gpredict

Introduction

During emergencies, radio communication is paramount and often readily provided by the Amateur Radio Emergency Services (ARES) and Radio Amateur Civil Emergency Service (RACES) groups within the amateur radio service. While a majority of amateur radio operators use terrestrial radio to provide communication during emergencies, low earth orbit (LEO) amateur radio satellites, which are available to “hams” worldwide, may also be used. Unfortunately, communication through LEO satellites is usually restricted to a particular terrestrial Earth location once a day, perhaps twice, and then

for only a 10-20 minute duration. Ultimately, a communication platform mounted on a geo-stationary Earth orbit (GEO) satellite would be a great benefit to amateur radio emergency communicators.

During a presentation at the 27th Annual American Radio Relay League (ARRL) and Tucson Amateur Packet Radio (TAPR) Digital Communication Conference, Dr. Tom Clark (K3IO) proposed mounting the Eagle radio communication module, currently under development by the Radio Amateur Satellite Corporation (AMSAT), on a yet-to-be-launched commercial GEO satellite. Dr. Clark envisioned that this new satellite would be located at 0.0° North latitude and 129.0° West longitude, and at an elevation of 35,780 Kilometers (Km) (Clark, 2008, September). He referred to this “bird” as GEO-Eagle and its theoretical “footprint” is shown as a dashed-line oval in Figure 1 (Clark, 2008, November).

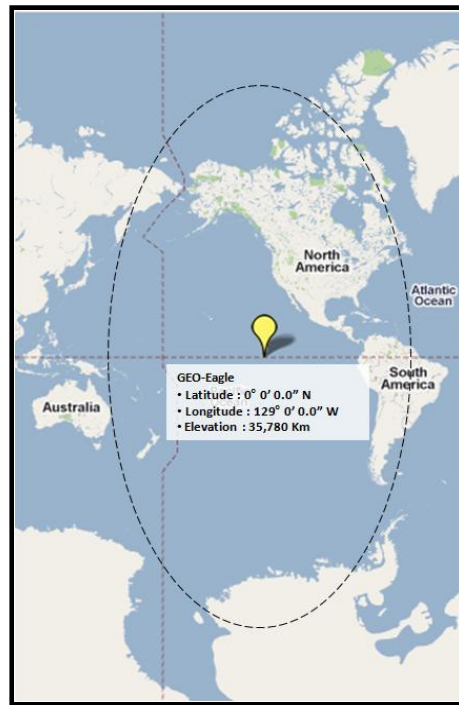


Figure 1: The theoretical footprint of K3IO’s proposed GEO-Eagle radio communication platform.

Additionally, Dr. Clark projected that GEO-Eagle’s uplink would be a 20 Megahertz (MHz) band in the 5650 through 5670 MHz frequency range (e.g. $\lambda = 13$ centimeters (cm), C-band) and the downlink would be a 10 MHz band in the 3400 through 3410 MHz frequency range (e.g. $\lambda = 9$ cm, S2-band). Given this uplink/downlink information and the “footprint” shown in Figure 1, we see that the GEO-Eagle radio communication platform would permit amateur radio operators to provide data communication services over a large geographic area using microwave frequencies. In contrast, similar long distance communication is currently accomplished with terrestrial radio using high frequencies.

During the months of March, April, and May 2009, we computed the time required to multicast data over a computer-simulated configuration of Dr. Clark’s GEO-Eagle radio communication platform using a personal computer and the Ns-2 network simulator. In this paper, we present the simulated data multicast transmission times obtained through our efforts. The intent of this research is to provide the amateur radio service with information detailing how much time will be required to multicast data over the GEO-Eagle radio communication platform when this satellite becomes available.

The structure of this paper is as follows. In the Background section we discuss the OSCAR IV satellite and data multicasts. We discuss the hardware and software we used to conduct our research in the Materials section. The Methods section describes the Ns-2 Tcl script we wrote and used to conduct our software simulations. We specifically describe values we chose for file size, transmission rate, and transmission delay. The transmission times generated by our software simulation, along with plots of our data, are presented in the Results section. The Conclusion section summarizes our discussion from the Results section. The Appendix contains tables of our data multicast transmission times as well as figures representing plots of specific transmission times shown in the tables.

Background

As described in the Introduction, Dr. Clark proposed mounting the AMSAT Eagle radio communication module on a commercial GEO satellite to create the GEO-Eagle radio communication platform. The OSCAR IV satellite, the amateur satellite community's first GEO satellite attempt, is discussed below. As will be discussed in the Methods section, we assume GEO-Eagle will be used to multicast data. Hence, a discussion of data multicast is also provided below.

OSCAR IV Satellite

Other than government, military, and commercial GEO satellites, no amateur satellites currently reside in geo-stationary Earth orbit. However, that is not because an attempt has not been made. On December 21st, 1965, the amateur satellite community attempted to place the OSCAR IV satellite into geo-stationary Earth orbit (AMSAT, 2009) (Ford, 2008). This satellite was launched into space aboard a Titan III-C rocket, but it only attained low earth orbit when the top stage of the rocket failed. The orbit of OSCAR IV ultimately decayed and was lost on April 12th, 1976 when it entered the Earth's atmosphere.

OSCAR IV was intended to function as a transponder with an uplink in the 432.1450 through 432.1550 MHz frequency range and a downlink in the 144.3000 through 144.3100 MHz frequency range. Based on the functionality provided by past amateur satellites, including OSCAR IV, we assume that the GEO-Eagle radio communication platform will also operate as a transponder, providing one or more channels for both voice and data. For the purpose of our research, we assume that one data channel will function as a repeater.

Data Multicasts

When transmitting data over wired transmission media, computers often use data unicast. During data unicast, which is referred to as point-to-point data communication, a source computer transmits packets to a destination computer. The destination computer sends an acknowledgement packet to the source when it receives one or more packets. The acknowledgement informs the source that the destination received the packet correctly. However, if a corrupt packet arrives at the destination, then the source will retransmit the packet later. Many of the traditional groups of Internet applications (e.g. tools), including electronic mail, news, remote login, and file transfer, use unicast to transmit data (Comer, 2007).

An alternative to data unicast is multicast, which can be used to transmit data over lossy wireless transmission media. During data multicast, a source computer transmits packets to multiple destination computers attached to the same network, but only subsets of all attached computers accept the multicast

packets. That is, only those computers that agree to accept packets from a specified multicast address do so. Unlike data unicast, the destination computer does not transmit acknowledgement packets. Instead, the source computer appends forward error correction (FEC) code to each packet transmitted. If the packet is corrupted during transmission, then the destination uses the FEC to retrieve the data transmitted by the source. Internet applications that use data multicast include University of California, Berkeley's *Open Mash Streaming Media Toolkit* (Rowe, 2002) and International Business Machines Corporation's *Content Manager VideoCharger* (IBM, 2010).

For the research discussed in this paper, we assumed data multicasts for two reasons. First, data multicast is often used over lossy wireless communication channels, such as satellites, because, unlike data unicast, multicast does not retransmit corrupted packets. Second, Udpcast, the multicast software we use to transmit data over AX.25 packet radio networks, is often used to multicast data over satellites (Knaff, 2006). For a discussion about data multicasts over terrestrial AX.25 packet radio networks, we refer the reader to (Wiedemeier, 2009 and 2008). The reader should consult (Wiedemeier, 2007) for information about data multicasts over simulated AX.25 packet radio networks.

Materials

To conduct simulations of data multicasts over Dr. Clark's proposed GEO-Eagle radio communication platform, we used a personal computer running the Linux operating system, the Ns-2 network simulator, and the Gpredict satellite tracking and orbit prediction application. We discuss the specific hardware and software used in the following paragraphs.

Fedora Linux

The personal computer we used to conduct our research was a Dell GX240 that was provided by The University of Louisiana at Monroe Digital Communication Research Laboratory. We installed the Fedora Linux, core 8, operating system with a KDE graphical interface on the PC and used command line windows to initiate our computer simulations. We chose to use Fedora Linux to conduct our research because, OpSim, another network simulator we use, requires a Fedora Linux installation.

Ns-2 Network Simulator

Several methods exist to model the transmission of data multicasts over communication networks, including live tests, test-beds, hardware emulation, simulation, and mathematical models (Allman and Falk, 1999). We used the Ns-2 network simulator, version 2.31 (Ns-2, 2010), for two reasons. First, Ns-2 is open source software and a version exists for the Linux operating system. Second, Ns-2 allows small research groups, such as ours, to simulate data transmission over proposed network topologies, such as GEO-Eagle. We refer the reader to (Wiedemeier, 2007) for a discussion about how to simulate data multicasts over AX.25 packet radio networks.

Gpredict Satellite Tracking and Orbit Prediction Application

We used the Gpredict satellite tracking and orbit prediction application to obtain slant range and 1-way delay (Gpredict, 2010). Specifically, slant-range represents the distance between a terrestrial location and a satellite. Likewise, the time in seconds required for a bit of data to move between a terrestrial location and a satellite is referred to as 1-way delay. We chose to simulate data multicasts from three terrestrial locations. Each location will be discussed in the Methods section of this paper. Similar to

Ns-2, we chose to use Gpredict because it is open source software and a version exists for the Linux operating system.

Methods

In general, all Ns-2 simulations are conducted through use of a Tcl script. The one we wrote and used is named *3N2L_CBR_UDP.tcl* and shown in Figures A5, A6, and A7 in the Appendix. To obtain a simulated transmission time using Ns-2, an individual executes the UNIX command *ns 3N2L_CBR_UDP.tcl*. During program execution, the Ns-2 network simulator generates a transmission time based on the defined logical Ns-2 simulation topology and the current variable values within in the Tcl script. The logical Ns-2 simulation topology we used is defined on lines 97-117 in Figures A6 and A7 in the Appendix and shown in Figure 2. The Tcl code that defines data multicast functionality is shown on lines 135 and 141 in Figure A7.

Our simulation topology is simple in that it contains a transmitter (Tx) node, the GEO-Eagle node, and a receiver (Rx) node. To obtain the maximum and minimum simulated data multicast transmission times, we assume the Tx and Rx nodes reside at the same terrestrial location. See Figure 2. We also assume that the GEO-Eagle radio communication platform functions as a transponder and, thus, acts as a passive entity during our simulation. That is, the satellite does not add extra transmission time to our simulations.

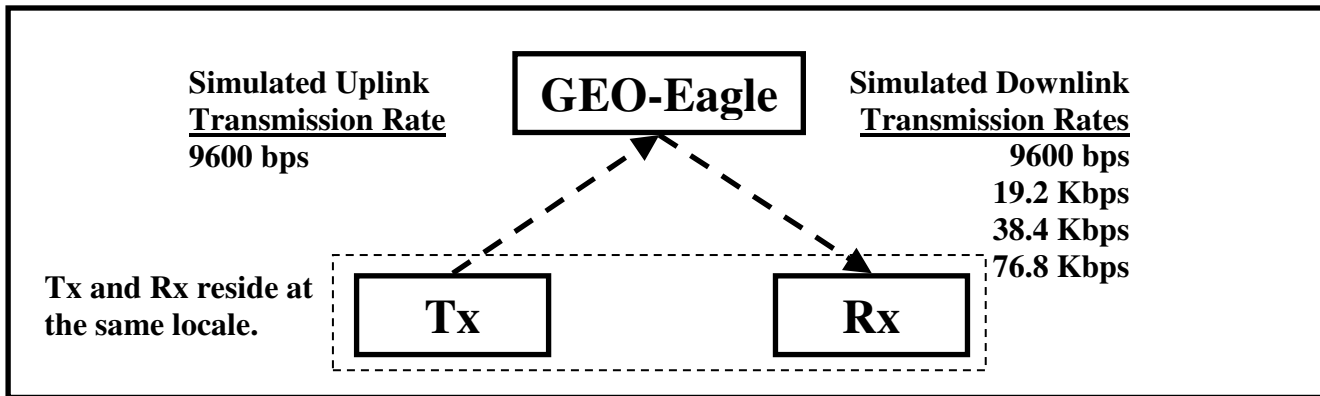


Figure 2: The logical GEO-Eagle Ns-2 simulation topology.

To generate simulated data multicasts, we executed Ns-2 against our Tcl script for various values of file size, transmission rate (i.e. bandwidth), and transmission delay. The values we chose for file size, transmission rate, and transmission delay will be discussed in the following paragraphs. For each file size, transmission rate, and transmission delay combination simulated, we recorded the transmission times generated by Ns-2 in a Microsoft Excel spreadsheet. See Tables A1, A2, and A3 in the Appendix. We next plotted the data transmission times for 4 Kilobytes (KB), 16 KB, 64 KB, and 1 Megabyte (MB) file sizes using the chart tool available in Microsoft Excel. See Figures A1, A2, A3, and A4 in the Appendix.

File Size

We chose to simulate data multicast using file sizes greater than or equal to 4 KB because 4 KB is the smallest file size Udpcast can transmit. Additionally, a 4 KB file is the approximate size of an ARRL

“filled-out” radiogram. We restricted the largest file size simulated to be 1 MB because this size represents a standard size Joint Photographic Experts Group (JPEG/JPG) or Bitmap (BMP) image, which has been the focus of our recent research (Wiedemeier, 2009). File size is defined on lines 59-63 in our Ns-2 Tcl script and shown in Figure A6 in the Appendix. Note that file size in our Ns-2 Tcl script is defined in bits and we simulated the transmission of 4 KB, 8 KB, 16 KB, 32 KB, 64 KB, 128 KB, 256 KB, 512 KB, and 1 MB sized files.

Transmission Rate

We chose to simulate data multicasts using an uplink transmission rate of 9600 bits per second (bps) and downlink transmission rates of 9600 bps, 19.2 Kilobits per second (Kbps), 34.4 Kbps, and 76.8 Kbps. Our choices for uplink and downlink transmission rates were influenced by a suggestion made by Dr. Mark Hammond (N8MH) to investigate the properties of the Symek TNC3S high-speed dual-port packet-controller (Hammond, 2009) (Symek, 2010). The uplink and downlink transmission rates are defined on lines 42-50 in our Ns-2 Tcl script and shown in Figure A5 in the Appendix. Note that transmission rate is defined in bits per second.

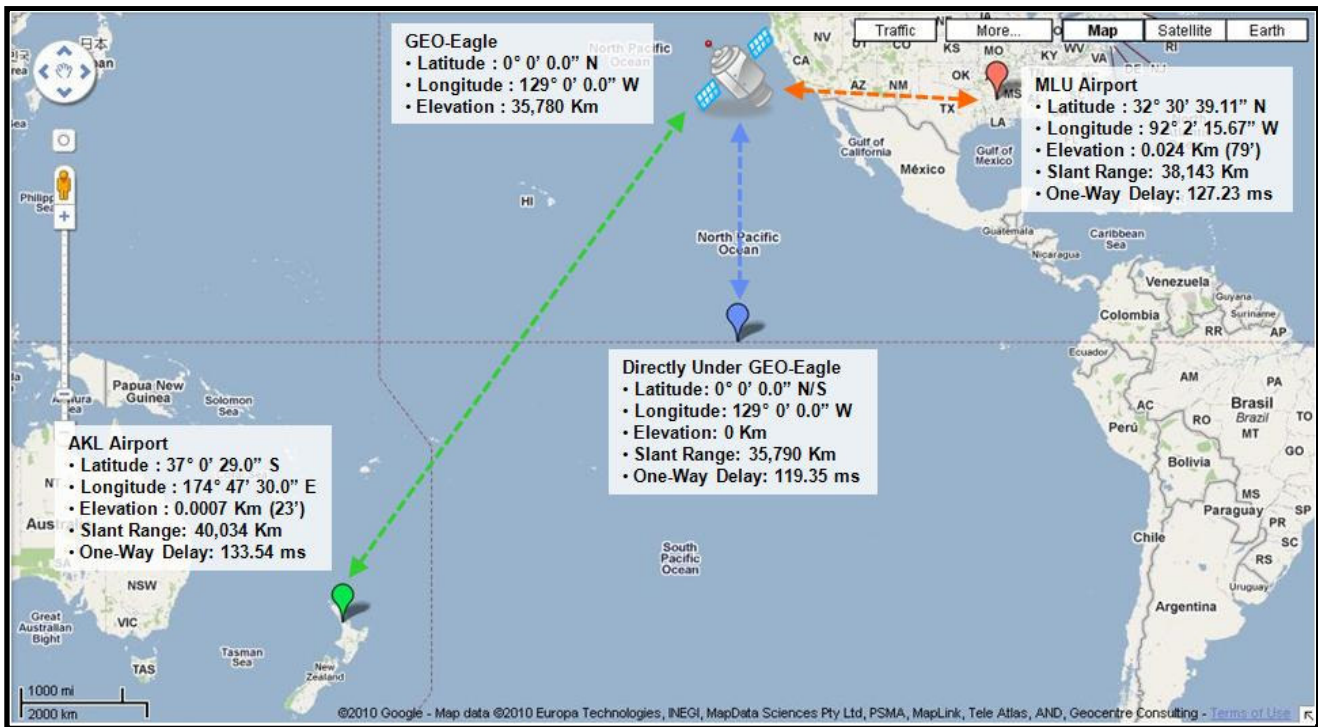


Figure 3: The physical location of the GEO-Eagle radio communication platform, the Tx/Rx pair directly under the GEO-Eagle radio communication platform, the Tx/Rx pair at the Auckland, New Zealand international airport, and the Tx/Rx pair at the Monroe, Louisiana airport.

Terrestrial Locations and Transmission Delay

As mentioned in the Materials section, we chose to simulate data multicasts between three terrestrial locations and GEO-Eagle. The three terrestrial locations we chose are shown in Figure 3. As stated in the Methods section, each terrestrial location contains a Tx and Rx. The first Tx/Rx pair is located directly under the GEO-Eagle satellite and is denoted by the acronym DUG in this paper. DUG resides

at 0.0° North latitude and 129.0° West longitude, and at an elevation of 0 Km (i.e. at sea level). The slant range for DUG is 35,790 Km and the one-way delay is 119.35 milliseconds (ms). We chose to simulate data multicasts between DUG and GEO-Eagle because the Tx/Rx pair should generate minimal transmission times compared to the other two terrestrial locations.

The second Tx/Rx pair is located at the Auckland, New Zealand international airport and is denoted by the acronym AKL in this paper. AKL resides at 37.0°, 0', 29.0" South latitude and 174.0°, 47' 30.0" East longitude, and at an elevation of 0.0007 Km. The slant range for AKL is 40,034 Km and the one-way delay is 133.54 ms. We chose to simulate data multicasts between this location and GEO-Eagle because Dr. Clark stated that Auckland, New Zealand would reside at the periphery of satellite's theoretical footprint. Thus, the AKL Tx/Rx pair should generate maximum transmission times compared to the other two terrestrial locations.

The third Tx/Rx pair is located at the Monroe, Louisiana airport and is denoted by the acronym MLU in this paper. MLU resides at 32.0°, 30', 39.11" North latitude and 92.0°, 2' 15.67" West longitude, and at an elevation of 0.024 Km. The slant range for MLU is 38,143 Km and the one-way delay is 127.23 ms. We chose to simulate data multicasts between this location and GEO-Eagle because this airport resides in this same city as our university. We expect simulated transmission times for data multicast between MLU and GEO-Eagle to be greater than those between DUG and GEO-Eagle, but less than those between AKL and GEO-Eagle.

The one-way delay values for DUG, AKL, and MLU discussed in the prior paragraphs are used to define transmission delay in the Ns-2 Tcl script *3N2L_CBR_UDP.tcl*. Specifically, transmission delay is defined on lines 52-55 in our Ns-2 Tcl script and shown in Figure A5 in the Appendix. Note that transmission delay is defined in seconds.

Results

The simulated data multicast transmission times generated by our Ns-2 script for 4 KB through 1 MB file sizes are shown in Tables A1, A2, and A3 in the Appendix. Those values that are bold, italic, and red if this document was printed in color, represent data multicasts that required two or more minutes of transmission time. We chose to highlight those data because a 100% duty cycle for transceivers that last longer than two-minute is significant.

With respect to the data shown in Tables A1, A2, and A3 in the Appendix, three features "stand out". First, the smallest file size, 4 KB, can be multicast in less than four seconds, even by the Tx/Rx pair at the Auckland, New Zealand international airport. As mentioned earlier, an ARRL radiogram is approximately 4 KB in size. Thus, it can be multicast by a TX to one or more RX within the GEO-Eagle "footprint" in approximately 4 seconds.

Second, a 128 KB file size is the largest that can be multicast in less than two minutes time for all transmission rates. Specifically, we see that files less than or equal to 128 KB in size can be multicast by the three Tx/Rx pairs and GEO-Eagle in approximately 109 seconds. For transmissions limited to one minute, our data show that file sizes less than or equal to 64 KB can be multicast in that amount of time or less.

Third, the simulated data multicast transmission times between the three Tx/Rx pairs and GEO-Eagle are approximately the same, with respect to whole seconds for all file sizes, save one. Specifically, if we ignore the fractional portion of the simulated transmission times (e.g. the thousandths), then the transmission times for all downlink transmission rate for a given file size are similar. This result is due to the slow 9600 bps uplink that dominates the data multicast transmission. The only exception, as mentioned earlier, is the 16 KB file size, where transmission times range from “high” 13 seconds to “low” 14 seconds.

The 4 KB, 16 KB, 64 KB, and 1 MB file size plots are shown in Figures A1, A2, A3, and A4 in the Appendix. As hypothesized, the time required to multicast the files between the DUG Tx/Rx pair and GEO-Eagle is less than the AKL and MLU Tx/Rx pairs. Likewise, the simulated data multicast transmission times generated between the AKL Tx/Rx pair and GEO-Eagle are greater than those for the DUG and MLU Tx/Rx pairs.

Conclusion

As discussed in the Results section, our data show the simulated data multicast transmission times between a pair Tx/Rx residing at one of three locations within the footprint of the GEO-Eagle satellite. Overall, a Tx/Rx pair located directly under the GEO-Eagle satellite requires the least amount of time to multicast data, whereas a Tx/Rx pair at the periphery of GEO-Eagle’s footprint (e.g. the Auckland, New Zealand international airport) requires the most amount of time to multicast the same data. Equally important, although not shown by our data, is that a Tx located within GEO-Eagle’s footprint can multicast data to one or more Rx residing within the same footprint. Specifically, the transmission time generated by a data multicast between any Tx and Rx within GEO-Eagle’s footprint will be greater than or equal to the time generated by a Tx/Rx pair located directly under the GEO-Eagle satellite, but less than or equal to the time generated by a Tx/Rx pair located at the satellite’s periphery.

As stated in the introduction, the purpose of this research is to simulate data multicasts over K3IO’s proposed GEO-Eagle radio communication platform. The authors’ intent is to present the amateur radio community, specifically those individuals who provide emergency communication, with data that can be used to make informed decisions concerning data communication over geo-stationary satellites, when such platforms become available. The authors hope these data communication resources are realized in the near future.

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Biography

Dr. Paul D. Wiedemeier is an Assistant Professor of Computer Science at The University of Louisiana at Monroe (ULM) and the principle investigator of the ULM Digital Communication Research Laboratory. Dr. Wiedemeier obtained a Ph.D. in Computer Engineering and Computer Science from the University of Missouri – Columbia, a M.S. in Computer Science from Michigan Technological University, and a B.S. in Computer Science from Drake University. He is a member of the Institute of Electrical and Electronics Engineers, the Association for Computing Machinery, the American Radio Relay League, the Tucson Amateur Packet Radio Corporation, the Consortium for Computing Sciences in Colleges, and the Louisiana Academy of Sciences. Dr. Wiedemeier also holds a General amateur radio license (KE5LKY) issued by the United States of America Federal Communications Commission.

Mr. Amir R. Shrestha is an undergraduate student at The University of Louisiana at Monroe pursuing a Bachelor of Science degree in Computer Science.

Release Form

I, Paul D. Wiedemeier, give permission to The Radio Amateur Satellite Corporation to publish our paper, "Characteristics of simulated data multicasts transmitted over K3IO's proposed GEO-Eagle communications platform", in the *Proceedings of the AMSAT-NA 28th Space Symposium and Annual Meeting*.

Appendix

Table A1: Simulated round trip data multicast transmission times (in seconds) for varied file sizes and downlink data transmission rates between the Tx/Rx pair located directly under the GEO-Eagle radio communication platform.

File Size	9600 bps	19.2 Kbps	38.4 Kbps	76.8 Kbps
4 KB	3.863	3.758	3.703	3.675
8 KB	7.279	7.172	7.119	7.092
16 KB	14.105	13.999	13.945	13.919
32 KB	27.758	27.648	27.598	27.570
64 KB	55.065	54.959	54.905	54.879
128 KB	109.678	109.568	109.518	109.490
256 KB	218.903	218.798	218.743	218.715
512 KB	437.359	437.252	437.199	437.172
1 MB	874.263	874.158	874.103	874.075

Table A3: Simulated round trip data multicast transmission times (in seconds) for varied file sizes and downlink data transmission rates between the Tx/Rx pair located at the Monroe, Louisiana airport.

File Size	9600 bps	19.2 Kbps	38.4 Kbps	76.8 Kbps
4 KB	3.877	3.771	3.717	3.694
8 KB	7.294	7.188	7.134	7.108
16 KB	14.121	14.014	13.961	13.934
32 KB	27.771	27.666	27.611	27.584
64 KB	55.081	54.974	54.921	54.894
128 KB	109.691	109.586	109.531	109.504
256 KB	218.917	218.811	218.757	218.734
512 KB	437.374	437.268	437.214	437.188
1 MB	874.277	874.171	874.117	874.094

Table A3: Simulated round trip data multicast transmission times (in seconds) for varied file sizes and downlink data transmission rates between the Tx/Rx pair located at the Auckland, New Zealand international airport.

File Size	9600 bps	19.2 Kbps	38.4 Kbps	76.8 Kbps
4 KB	3.890	3.785	3.730	3.703
8 KB	7.307	7.200	7.147	7.120
16 KB	14.134	14.027	13.974	13.947
32 KB	27.785	27.680	27.625	27.598
64 KB	55.094	54.987	54.934	54.907
128 KB	109.705	109.600	109.545	109.518
256 KB	218.930	218.825	218.770	218.743
512 KB	437.387	437.280	437.227	437.200
1 MB	874.290	874.185	874.130	874.103

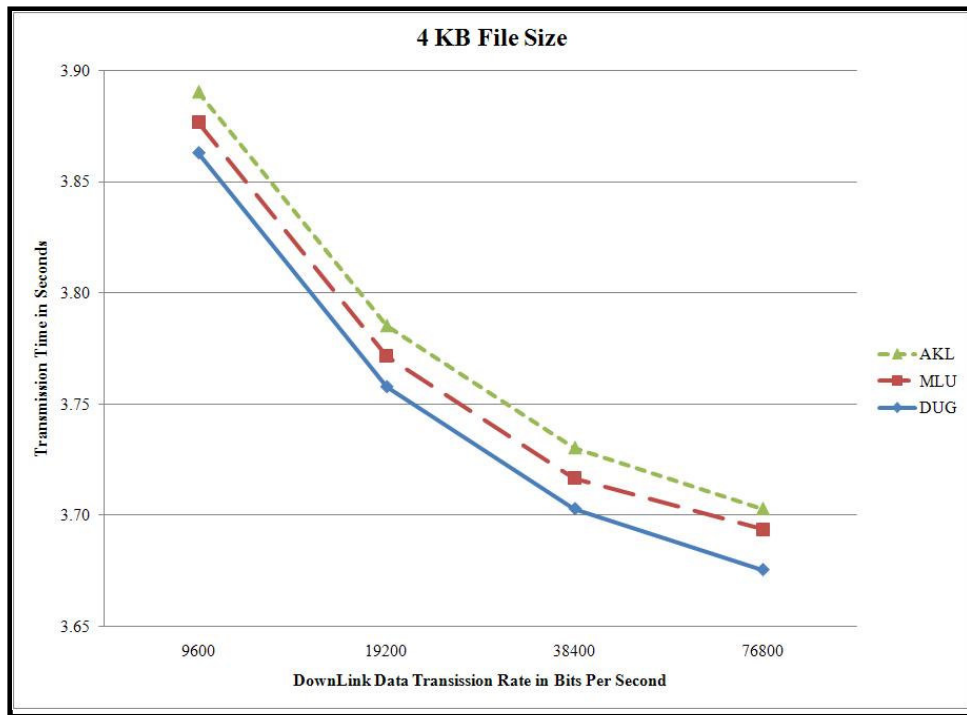


Figure A1: Simulated round trip 4 KB multicast transmission times between the three Tx/Rx pairs and the GEO-Eagle radio communication platform.

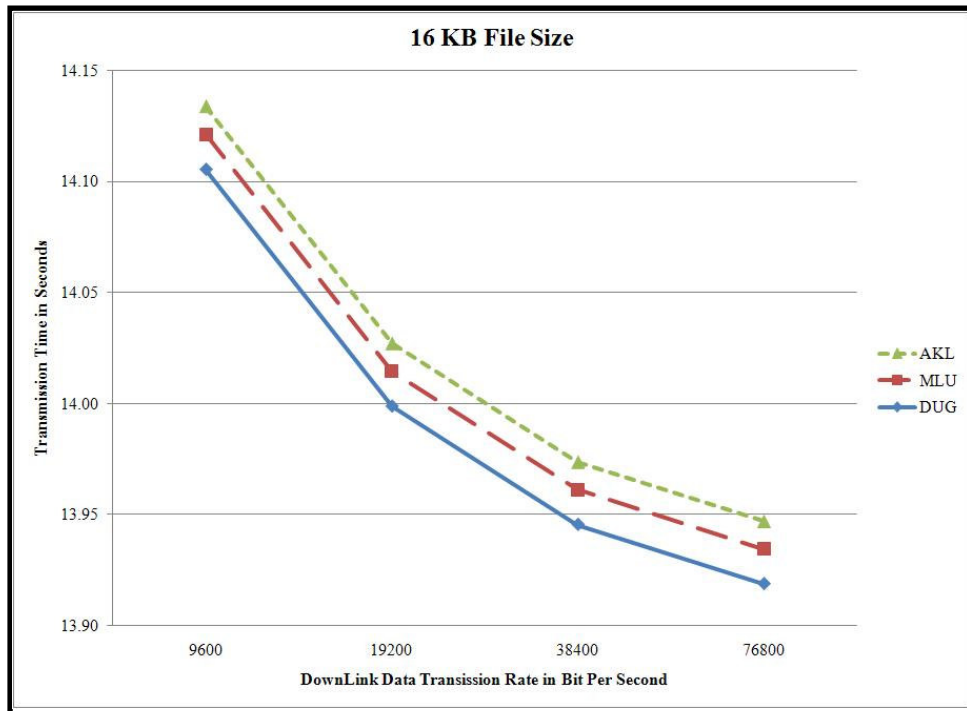


Figure A2: Simulated round trip 16 KB multicast transmission times between the three Tx/Rx pairs and the GEO-Eagle radio communication platform.

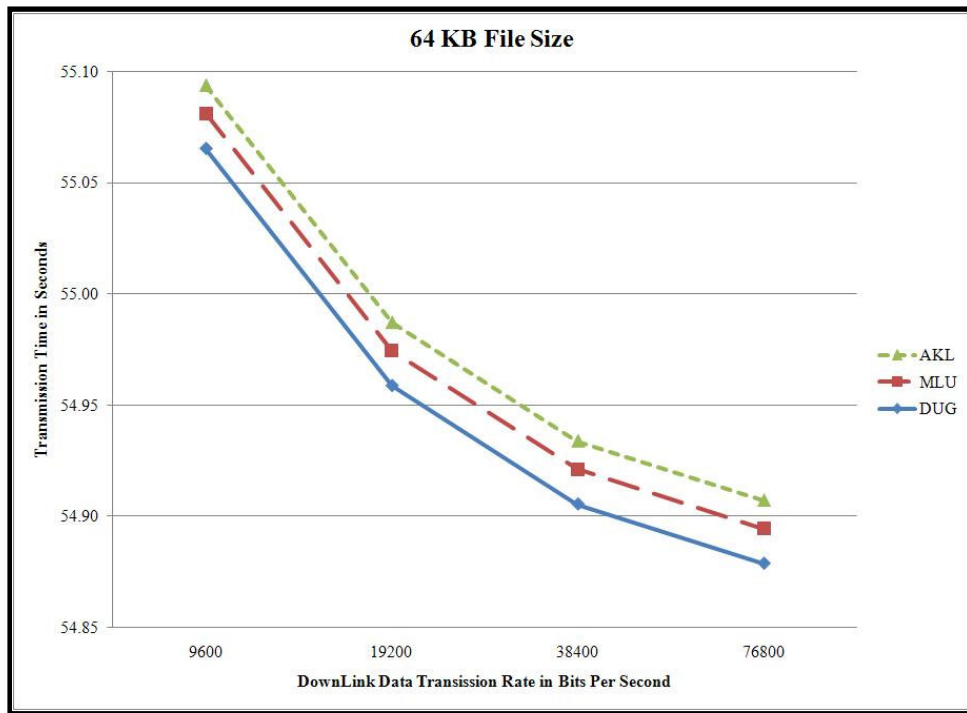


Figure A3: Simulated round trip 64 KB multicast transmission times between the three Tx/Rx pairs and the GEO-Eagle radio communication platform.

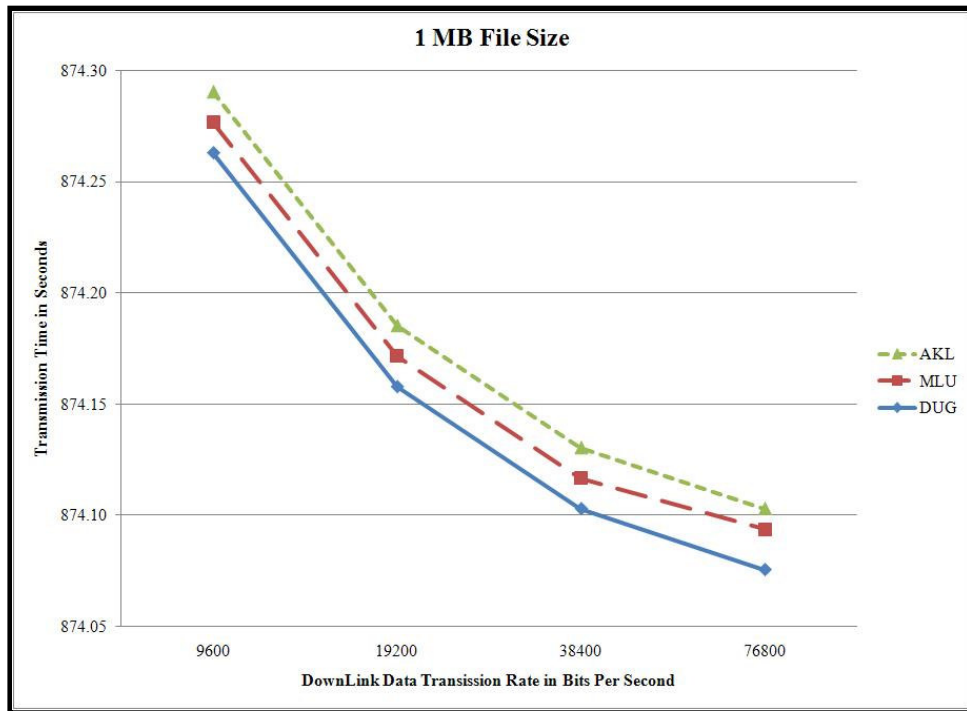


Figure A4: Simulated round trip 1 MB multicast transmission times between the three Tx/Rx pairs and the GEO-Eagle radio communication platform.

```

1 #####
2 #
3 # Program Name: 3N2L_CBR_UDP.tcl
4 #
5 # Author: Paul D. Wiedemeier, Ph.D.
6 # Date Written: July 2007
7 # Date Modified: March 2009
8 #
9 # Organization: The University of Louisiana at Monroe
10 # Address: 700 University Avenue
11 # Hemphill Airways and Computer Science Building, Room 348
12 # Monroe, Louisiana 71209
13 # Work Phone: 318-342-1856
14 # Email: wiedemeier@ulm.edu, wiedemeierp@gmail.com, or KE5LKY@arrl.net
15 # URL: http://www.cs.ulm.edu/~pdw/
16 #
17 #####
18
19 #####
20 # define a 'finish' procedure
21 #####
22
23 proc finish {} {
24     global ns opt
25     global filed
26     $ns flush-trace
27     close $filed(tr)
28     close $filed(namtr)
29     exit 0
30 }
31
32 #####
33 # define variables
34 #####
35
36 # start simulation at 0.0 seconds
37 set opt(start_time) 0.0
38
39 # stop simulation after 100000.0 seconds
40 set opt(stop_time) 100000.0
41
42 # Uplink Transmission rate (i.e. bandwidth) in bits per second
43 # 9600
44 set opt(bw_up) 9600
45 puts stdout "bw_up = $opt(bw_up) "
46
47 # Downlink Transmission rate (i.e. bandwidth) in bits per second
48 # 9600, 19200, 38400, 76800
49 set opt(bw_dn) 76800
50 puts stdout "bw_dn = $opt(bw_dn) "
51
52 # Transmission Delay (link) in seconds
53 # DUG = 0.11935, MLU = 0.12723, AKL = 0.13354
54 set opt(del) 0.13354
55 puts stdout "del = $opt(del) "
56
57 set opt(ifq) DropTail
58

```

Figure A5: Lines 1-58 from Ns-2 Tcl script *3N2L_CBR_UDP.tcl*.

```

59 # File Size in bits
60 # 4KB = 32768, 8KB = 65536, 16KB = 131072, 32KB = 262144, 64KB = 524288,
61 # 128KB = 1048576, 256KB = 2097152, 512KB = 4194304, 1MB = 8388608
62 set opt(file_size) 8388608
63 puts stdout "file size = $opt(file_size)"
64
65 # Segment Size in bytes. The default Ns-2 simulator Segment Size is 1KB
66 set opt(sgmt_size) 256
67 puts stdout "sgmt size = $opt(sgmt_size)"
68
69 # Segment Interval Transmission Time
70 set opt(sgmt_int) [expr [expr [expr [expr $opt(sgmt_size) * 8.0] / $opt(bw_up)] +
    $opt(del)] + [expr [expr [expr $opt(sgmt_size) * 8.0] / $opt(bw_dn)] + $opt(del)]]
71 puts stdout "sgmt interval = $opt(sgmt_int)"
72
73 set opt(src) UDP
74 set opt(sink) Null
75 set opt(app) Traffic/CBR
76
77 #####
78 # begin main
79 #####
80
81 set ns [new Simulator]
82
83 #####
84 # open trace file descriptor
85 #####
86
87 set filed(tr) [open "out.tr" w]
88 $ns trace-all $filed(tr)
89
90 #####
91 # open nam trace file descriptor
92 #####
93
94 set filed(namtr) [open "out.nam" w]
95 $ns namtrace-all $filed(namtr)
96
97 #####
98 # create topology
99 #####
100 #
101 # +-----+ +-----+ +-----+
102 # | | Uplink | GEO-Eagle | Downlink | |
103 # | Tx |----->| |----->| Rx |
104 # | | | | |
105 # +-----+ +-----+ +-----+
106 #
107 #####
108
109 set node(tx) [$ns node]
110 set node(geoeagle) [$ns node]
111 set node(rx) [$ns node]
112
113 $ns duplex-link $node(tx) $node(geoeagle) $opt(bw_up) $opt(del) $opt(ifq)
114 $ns queue-limit $node(tx) $node(geoeagle) 65536
115

```

Figure A6: Lines 59-115 from Ns-2 Tcl script *3N2L_CBR_UDP.tcl*.

```

116 $ns duplex-link $node(geoeagle) $node(rx) $opt(bw_dn) $opt(del) $opt(ifq)
117 $ns queue-limit $node(geoeagle) $node(rx) 65536
118
119 #####
120 # create traffic flow - part 1
121 #####
122
123 Application/Traffic/CBR set packetSize_ $opt(sgmt_size)
124 Application/Traffic/CBR set interval_ $opt(sgmt_int)
125 Agent/UDP set packetSize_ $opt(sgmt_size)
126
127 #####
128 # create traffic flow - part 2
129 #####
130
131 # red, blue, green, orange, brown, darkgreen, purple, black, etc.
132 set color(0) red
133 $ns color 0 $color(0)
134
135 set udp0 [$ns create-connection $opt(src) $node(tx) $opt(sink) $node(rx) 0]
136
137 #####
138 # create traffic flow - part 3
139 #####
140
141 set cbr0 [$udp0 attach-app $opt(app)]
142
143 #####
144 # start traffic flow
145 #####
146
147 set opt(num_sgmts) [expr $opt(file_size) / [expr $opt(sgmt_size) * 8.0 ]]
148 puts stdout "num sgmts = $opt(num_sgmts)"
149
150 set opt(stop_time) [expr [expr [expr [expr [expr $opt(sgmt_size) * 8.0] *
    $opt(num_sgmts)] / $opt(bw_up)] + $opt(del)] + [expr [expr [expr $opt(sgmt_size) *
    8.0] / $opt(bw_dn)] + $opt(del)]]
151 puts stdout "stop time = $opt(stop_time)"
152
153 $ns at $opt(start_time) "$cbr0 start"
154
155 #####
156 # call 'finish' procedure when done
157 #####
158
159 $ns at $opt(stop_time) "$cbr0 stop"
160 $ns at $opt(stop_time) "finish"
161
162 #####
163 # start the simulator
164 #####
165
166 $ns run
167
168 #####
169 # exit gracefully
170 #####
171
172 exit 0

```

Figure A7: Lines 116-172 from Ns-2 Tcl script *3N2L_CBR_UDP.tcl*.

HamTV Experiment on-board ISS

HamTV – An Amsat-Italia proposal and preliminary tests for a DVB-S Amateur TV transmission from the International Space Station.

F. Azzarello IW8QKU, E. D'Andria IØELE, T. Giagnacovo IZØLTG, P. Tognolatti IØKPT
Corresponding author: Fabio Azzarello, email: iw8qku@amsat.org

Abstract

Scope of this paper is to present an experiment of digital video transmission from the International Space Station. It could be a challenging experiment for amateurs interested in television tests and a complement of the half-duplex voice link carried out within the ARISS school contacts activities.

The paper will start with the process of identification of the most suitable frequency band and of the standard technology for a video transmission (Analog or Digital) and will proceed with the identification of the most suitable commercial off-the-shelf (COTS) hardware as a solution for the implementation of the payload.

First lab experiments results will be also presented as well as an architecture of the receiving earth station.

The payload is intended to be embarked on the Columbus module of the ISS where an amateur station will be installed and operated. It will use the VHF/UHF and S-Band antennas already placed outside the European module.

Introduction

The installation of S-band equipment in Columbus module will open a new era for Amateurs as well for ARISS School Contacts.

In combination with VHF audio the HAMTV downlink will provide schools and amateurs, all over the world, a real time view inside the ISS.

A television beacon mode will be also foreseen to allow amateurs to experiment with different downlink configurations.

The sequence of voice and video sent down to the earth will be captivating, procuring a very intense experience of the pass of the ISS over the ground station.

For direct contacts, the equipment will be more complex than for audio contacts: an S-band receiver will be needed with an appropriate directive antenna as well as the complete HAMTV equipment.

Frequency Band Selection

A preliminary investigation of the UHF, L and S Bands allocated to the radio amateur service, aiming at selecting the proper frequency band for the HAMTV experiment from the International Space Station, has identified the S-Band to be the best candidate for the HAMTV Experiment.

This band can handle both digital and analogue television, because of the necessary bandwidth for the transmission of a television signal, and it can guarantee enough link margin by using high-gain antenna.

On the other hand, S-Band is heavily used on-board the ISS: bands are allocated to the Space Operations Service (i.e. 2025-2100 MHz ↑ and 2200-2290 MHz ↓) and, in addition, there is a Wi-Fi activity on-board in the frequency band 2400-2483.5 MHz which overlaps with the HAMTV frequencies (2400-2450 MHz).

However, the S-Band could be compatible with the Space Operation Service of the ISS if an appropriate filtering of the receiver and of the HAMTV transmitter is present, this need to be proved.

It has to be noted that Wi-Fi terminals are able to operate in an interfering environment (ISM Bands) but in order to minimize the potential interference it is suggested to adopt an HAMTV modulation scheme which requires less power and less bandwidth.

In addition a shielding effect could be considered due to the fact that the HAMTV transmitter will radiate outside the Columbus module while the Wi-Fi networks are intended to be used inside the ISS, this should improve their electromagnetic compatibility. A further improvement can be obtained with a careful selection of the HAMTV frequency carrier (i.e. channel 3 at 2.422 GHz) in a empty portion of the spectrum.

Since the S-Band is really crowded a possible solution is to propose a modification of the IARU Band Plan to allow amateur satellite applications outside the ISM frequency bands.

Analog or Digital

To evaluate the best technology to use, in order to make contacts more reliable, a number of different approach was faced. Link budget calculations were done for both analog and digital systems [REF1,2] over the three band of interest.

As first selection the L band was abandoned, even if it was the most promising, because of regulatory constraints (L band cannot be used for any space downlink).

Operating frequency	435-438 MHz		1260-1270 MHz		2400-2450 MHz	
Modulation type	ANALOG FM	DIGITAL DVB-S	ANALOG FM	DIGITAL DVB-S	ANALOG FM	DIGITAL DVB-S
Link budgets assumptions (antenna gains, losses, intermodulation, etc)	N.A. Band limitation	QPSK FEC 1/2 FEC 7/8	N.A. Downlink restrictions	N.A. Downlink restrictions	FM 16 MHz-pp	QPSK FEC 1/2
On board RF output power (with estimated back-off, efficiency and resulting DC power consumption)	N.A.	10 W	N.A.	N.A.	10 W	10 W
Instantaneous bandwidth	-	2.93 MHz 1.67 MHz	-	-	28 MHz	1.35 MHz
Link Budget Margin	-	+13.8 dB +11.9 dB	-	-	-10.4 dB	+6.9 dB

Table 1 – Technology summary

Table 1 shows the last selected parameters [REF 3], a preliminary detailed link budget will follow. The choice was almost driven to the S band because of the quite good availability of COTS hardware at low cost. The 70 centimetres band was also abandoned because of strong interference from ground based services in Italy, COTS were also not so easy to find like for S-Band.

Link Budget Details

In this section link budget for the HAMTV system is presented. The following Table 2 shows the most important parameters/values involved in the radiofrequency link-budget as a comparison between the two standards.

DVB-S - ArCOL LINK BUDGET			FM ATV - ArCOL LINK BUDGET		
	Value	Unit		Value	Unit
Downlink frequency	2.450	GHz	Downlink frequency	2.450	GHz
Boltzmann's constant	-228.60	dBW/K-Hz	Boltzmann's constant	-228.60	dBW/K-Hz
ISS to E/S range	1000	Km	ISS to E/S range	1000	Km
EARTH STATION CHARACTERISTICS					
Antenna diameter	0.90	meters	Antenna diameter	0.90	meters
Efficiency	50%		Efficiency	50%	
Rx Antenna gain	24.3	dBi	Rx Antenna gain	24.3	dBi
Antenna Noise Temperature (¹)	100	K	Antenna Noise Temperature (¹)	100	K
Implementation losses	0.0	dB	Implementation losses	0.0	dB
Implementation equiv noise temp	0.0	K	Implementation equiv noise temp	0.0	K
Antenna pointing losses	0.0	dB	Antenna pointing losses	0.0	dB
Antenna pointing losses equiv noise temp	0.0	K	Antenna pointing losses equiv noise temp	0.0	K
LNB gain	35	dB	LNB gain	35	dB
LNB noise figure	0.8	dB	LNB noise figure	0.8	dB
LNB equiv noise temp	58.7	K	LNB equiv noise temp	58.7	K
FIGURE of MERIT G/T					
System Noise Temp	158.7	K	System Noise Temp	158.7	K
System Noise Figure	1.9	dB	System Noise Figure	1.9	dB
G/T	2.3	dB/K	G/T	2.3	dB/K
CARRIER CHARACTERISTICS					
Data Rate	922	kbps	Peak to Peak frequency deviation ΔF_{pp}	16	MHz
Reed Solomon	188/204		TV signal bandwidth B_v	6	MHz
Modulation	QPSK		Modulation	FM	
FEC	1/2		Carrier's occupied bandwidth	28	MHz
Symbol Rate	1000	kbaud	<i>pw [Unified] CCIRR Rep. 637 pre/de-emphasis gain</i> ²	13.2	dB

¹ Antenna noise temperature DO NOT include noise contributions from interfering systems close to the receiving station (e.g. WiFi access point, microwave ovens, video senders, radio links, etc.).

A preliminary measurement of G/T is strongly recommended. Sun-noise measurement at sunrise or sunset should be a convenient method to test RX station figure-of-merit at low elevations.

Mod. Factor (2=QPSK, 3=8PSK, ..)	2				
Brutto BitRate	2000	kbps			
Roll-off (%)	0.35				
Carrier's occupied bandwidth	1.35	MHz			
DOWNLINK					
TX power	10.0	dBW	TX power	10.0	dBW
cable & connector losses	7.0	dB	cable & connector losses	7.0	dB
TX Antenna gain (boresight)	8.0	dB	TX Antenna gain (boresight)	8.0	dB
pointing losses	10.5	dB	pointing losses	10.5	dB
Downlink e.i.r.p. toward earth rx station	0.5	dBW	Downlink e.i.r.p. toward earth rx station	0.5	dBW
Downlink path loss (free space)	160.3	dB	Downlink path loss (free space)	160.3	dB
Atmospheric losses	0.0	dB	Atmospheric losses	0.0	dB
Noise increase due to precipitation	0.0	dB	Noise increase due to precipitation	0.0	dB
Rain attenuation losses	0.0	dB	Rain attenuation losses	0.0	dB
			C/N (Available)	-3.4	dB
C/No	71.1	dBHz	C/N (required due to demod. threshold)	7.0	dB
C/N	9.8	dB	Margin on C/N	-10.4	dB
Eb/No (Available)	11.4	dB	S/N (Required for P3 video quality)	25.0	dB
Eb/No (Required)	4.5	dB	C/N0 (available)	71.1	dBHz
Link Margin	6.9	dB	C/N0 (Required for P3 quality)	69.3	dBHz
			Margin on C/N0	1.8	dB
			Link Margin	-10.4	dB

Table 2 – Link Budget Comparison

Once we have selected the first optimized parameters for the DVB-S transmission (output power, transmission rate and so on) we have summarized the link budget calculations on the following Fig. 1, (left side). On the right panel of the same figure it is possible to evaluate the attenuation due to rain, as showed it could be considered negligible at the selected frequencies [REF 4].

² For reference see pages 8-20 in: <http://www.authorstream.com/Presentation/Gavril-30933-satcommsspring2005-Satellite-Communications-BSpring-Semester-2004-5-Broadcasting-Contents-Analogue-System-model-FDM-FM-as-Entertainment-ppt-powerpoint/> or Dennis Roddy, "Satellite Communications", 3rd Ed., McGraw-Hill, 2001.

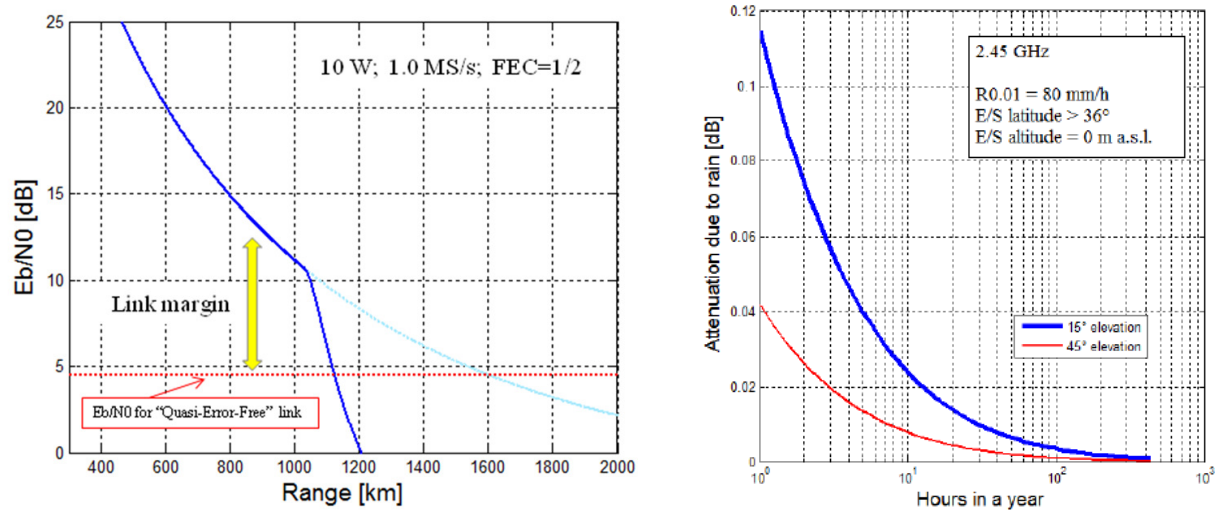


Figure 1 – Left panel: link margin vs. range, for DVB-S and system parameters as in Table 2; the dashed light-colored curve shows the behavior if the antenna temperature were 100 K for every elevation, i.e. if ground thermal noise and interferences were neglected. Right panel: rain attenuation vs. time percentage.

Payload

In this section the HamTV transmitter concept is outlined.

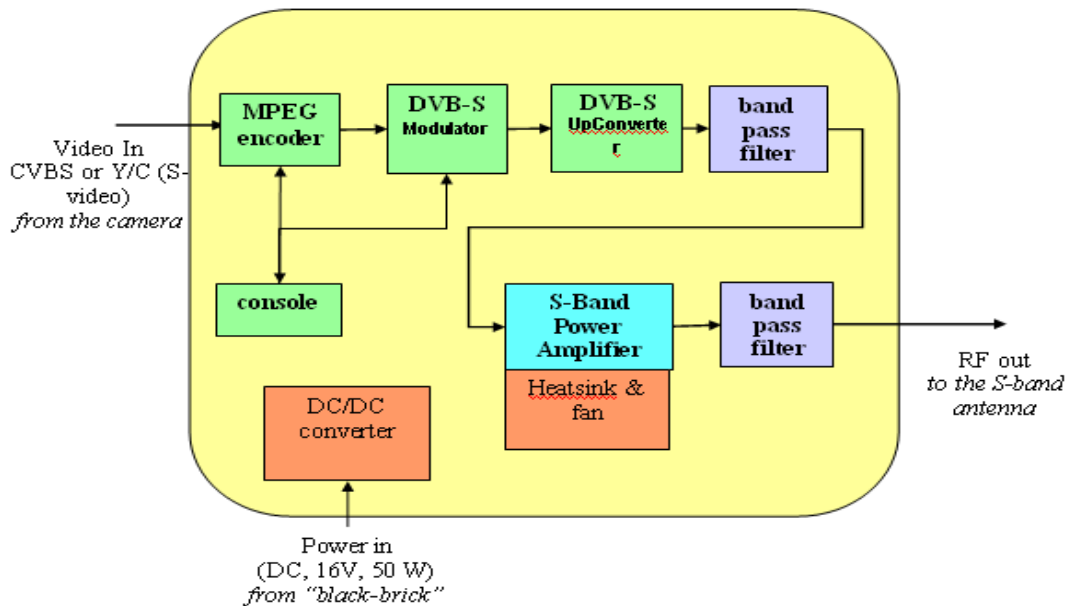


Figure 2 - HamTV transmitter block diagram

The block diagram in Figure 2 should be detailed enough: the video source could be a common camcorder that feeds the HamTV system. The encoder translates the input in a MPEG stream which will be modulated to the S-band with the selected modulation scheme and then transmitted to the Ground Stations.

The COTS components that we have selected for testing, are among the most widely used in the ham radio community, this should also guarantee a sufficient capability to use and operate such equipments.

First experiments and results

The following schematic shows the AMSAT-I laboratory setup at IZØLTG labs.

This setup is designed to assess the main performances of MPEG encoding at different FEC rates, coding parameters and to measure receiver's performances at different Signal-to-Noise ratios. All measurements were run in "IF-loop" mode, which means that the connection between TX and RX is performed at IF signal (at about 1 GHz). The spectrum analyzer shows the emission of the setup.

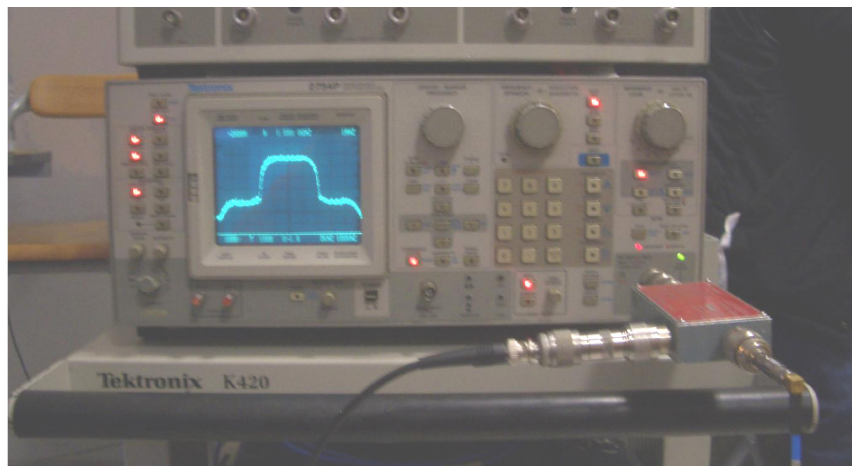
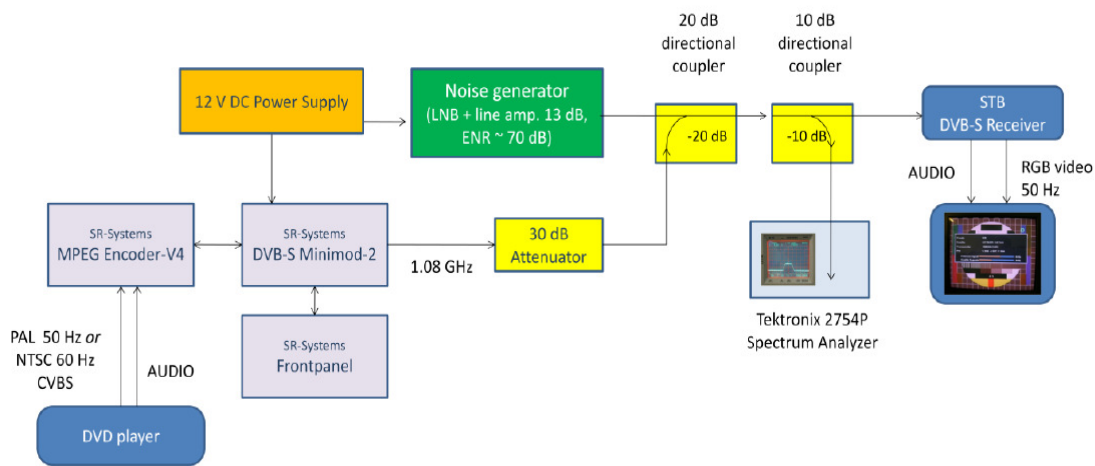


Figure 3 - Laboratory setup for IF-loop measurements on HamTV system.

Ground Station Architecture

A basic radio amateur station able to receive HamTV from ISS is proposed in the following Figure 4

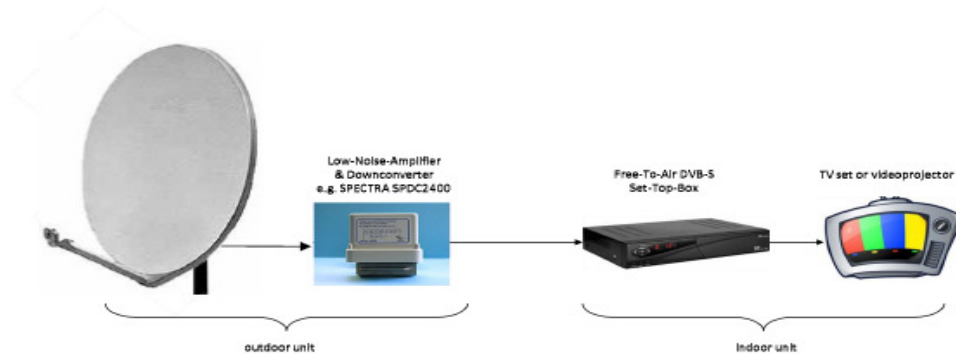


Figure 4 - Ground Station architecture

The receiving system, of course, is designed taking into account link budget calculations shown in Table 2. A 90cm dish with proper feeding should be adequate enough to reach minimum system requirements. Side lobe suppression and G/F figure optimization must be pursued. Since patch antenna on-board ISS are circularly polarized (RHCP), also ground stations must be equipped with circular polarized antenna feeds.

Conclusions

First lab tests results make us confident that the link will be reliable enough to guarantee successful contacts. Other tests are ongoing, we're trying to verify that even in marginal conditions the system will perform correctly, we are also checking the possibility to extend the link duration using multiple stations (chains).

Authors would like to acknowledge valuable discussions on HamTV with Francesco De Paolis I40WGF, Marco Lisi IZ0FNO, Ottorino Odoardi IZ6BMP, Paolo Pitacco IW3QBN, Pierluigi Poggi IW4BLG and with Gaston Bertels ON4WF together with the ARISS/ARCOL WG.

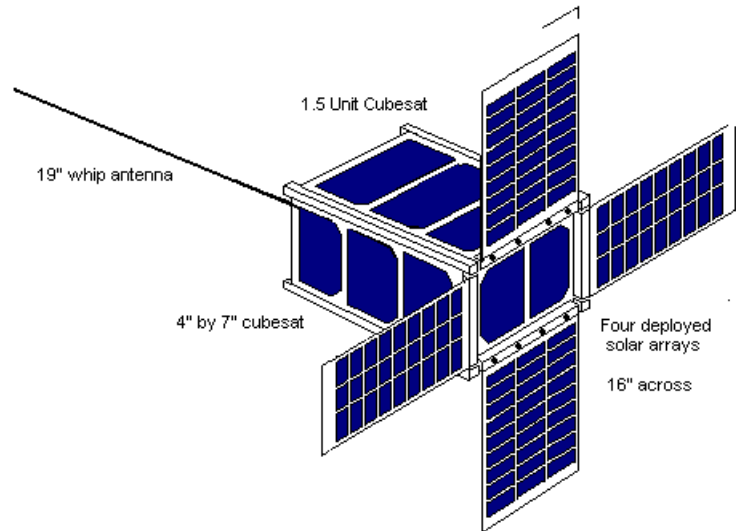
References

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- [REF 3] - Amsat-Italia Doc HamTV 002 Issue 2 - 21 April 2010
- [REF 4] - ITU-R P.618-7 - Propagation data and prediction methods required for the design of Earth-space telecommunication systems.

Psat and the APRS Space Network

Bob Bruninga, WB4APR
TAPR/ARRL/AMSAT/USNA
Annapolis, Maryland

Abstract: *The next APRS satellite is manifest for launch in the spring of 2011. This will be our first cubesat, but with four deployable solar panels we should have plenty of power budget for an APRS VHF as well as a PSK-31 ten-meter transponder. APRS is a communications text-messaging and information receive system for the distribution and display of relevant immediate information of use to the mobile or portable operator. Via the APRS Amateur Satellites, this capability is extended world-wide from a radio in the palm of your hand.!*



Many people have been misled into thinking of APRS as a vehicle tracking system and thus dead-end their thoughts about how to use this 2-way communications capability for universal text messaging. As originally designed, APRS focuses on the receipt and display of relevant ham radio information and text-messaging and Email from the palm of your hand and APRS represents the epitome of ham radio. With our congested and shared AMSAT uplinks, the ability to transmit your relevant QSO information through the satellite in about 1 second is very valuable to the use by large numbers of operators. Most cubesats and other university satellites are capable of serving as APRS transponders, even while they are performing their primary mission. We need to encourage such operations, preferably on the one 145.825 channel for synergy with other satellites and the global network of ground stations.

Key Words: Psat, APRS, ham radio text messaging, Satellite Objects

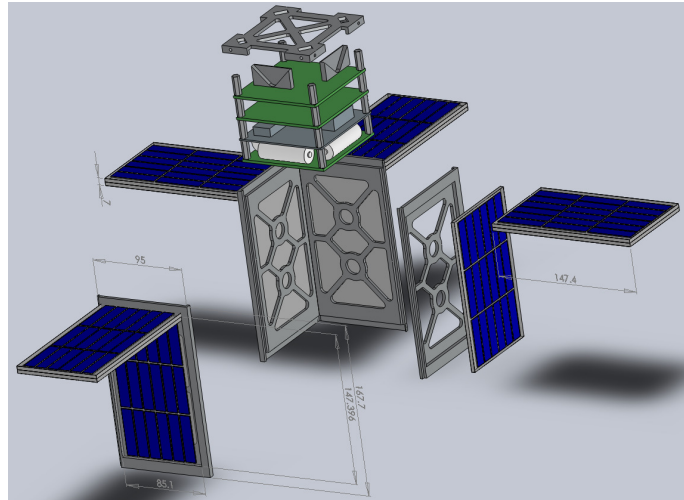
APRS in Space: No matter where you are on the planet from about 2001, if you had your APRS radio with you, there was a communications opportunity on the order of every few hours or so via the APRS satellites (ISS, PCSAT, PCSAT2, ANDE, RAFTm GO-32, ECHO and some cubesats. You can uplink to these satellites with as little as a 5 Watt HT and whip antenna or via your mobile with omni antenna. There is no reason why we cannot support many more APRS transponders on the many cubesats and other small student and university satellites on 145.825 MHz.

Most hams even in 2010 do not realize that APRS operators have been able to use their radios for local/global text messaging and Emails for the last 10 years? This was long before the present teenager craze of text messaging on cell phones. See <http://aprs.org/aprs-messaging.html> [1].

Text messaging is as fundamental to ham radio communications as CW was in Marconi's time. Minimum communications is also important when there is a local situation, emergency, disaster, or simply when something exciting is happening that you want to share with others. We equip our cars with amateur radio technology, but are we really using it effectively? With APRS satellites able to work with mobiles and omni antennas, it is important that AMSAT operators be aware of this communications capability.

ParkinsonSAT (Psat)

Psat is the next APRS satellite design from students at the US Naval Academy. Although we have built 5 previous APRS satellites, only the original PCSAT-1 is still in orbit because all the others were deployed from the Shuttle and at the low altitude, have re-entered. PCSAT-1 (W3ADO-1) is partially operational when ever sun angles are optimum a few times a day; and you can see its live downlink on <http://pcsat.aprs.org> [2].



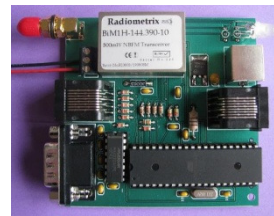
Psat will be our first CUBESAT designed around the 4" cubesat concept developed by Bob Twiggs at Stanford over a decade ago and now organized by Cal Poly. Instead of a single 4" cubesat, our design consists of two 1.5 unit cubesats to completely occupy a single P-Pod Deployer. In order to close the link between mobiles and the satellites, both using OMNI antennas, we are using a 4Watt packet transmitter. There is insufficient power available on a cubesat to maintain this power budget. So Psat includes four deployable solar panels to more than double the power available. See the Psat design page [3]

Attitude Control System

Of course, the deployable solar panels are of no value unless they can be pointed directly at the sun. This requires an Attitude Dynamics and Control System. The ADCS consists of a sun sensor, a magnetometer and a set of three orthogonal torque coils. It senses its attitude with respect to the sun and senses its orientation with respect to the local magnetic field, then it computes the needed torque to apply to the proper coils to not only bring it into alignment with the sun, but also to maintain a slow spin about the sun axis so that it will coast through eclipse and be reasonably pointed at the sun when it comes back out of eclipse.

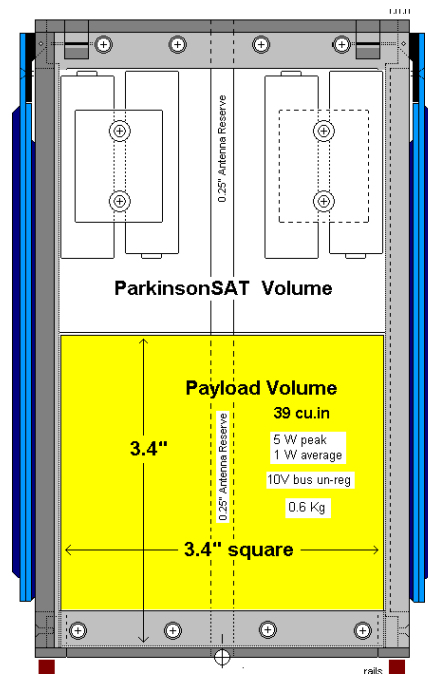
We are using a very simple Parallax BASIC Stamp processor for all onboard functions and ADCS. This is a challenge in a processor with only 16 words of RAM and only 2K of program memory. Fortunately, the high-end BS2pe processor extends the capability by allowing 8 different pages of 2K program space and adds 128 bytes of scratchpad memory. The other challenge is that there is no floating point and multiplication and division are limited to positive integers only!

APRS Transponder: Inherent in any AX.25 packet system for spacecraft is the ability to support the APRS digipeating function. Our previous satellites simply flew a conventional TNC (Terminal Node Controller) in space, and not only did this provide the APRS function, the TNC's also included remote-sysop control capabilities and some analog telemetry inputs so the stock TNC's processor without any significant modification could be used for spacecraft command and control as well. What made this new Cubesat version possible was the recent off-the-shelf combination of a full function TNC and micro transceiver in the Byonics MT-TT4 Microtrack APRS system. The change in size from the original PCSAT 1 and 2 APRS transponder tray and the new Microtrack MT-TT4 is shown in the figures below:



Auxilliary Payload (Ten Meter PSK-31 Band Monitor):

The APRS relay function is inherent in the basic communications modules and TNC of the Psat bus. Therefore, that function complete with battery power system and ADCS fits in less than half of the available 1.5Unit cubesat. This allows the other half to be used for auxiliary payloads. One such potential amateur payload is a PSK-31 Transponder. Using PSK-31 on the uplink allows as many as 30 or more simultaneous users to use the narrow 3 KHz uplink bandwidth into an SSB type receiver. The combination of all these signals is then downlinked on a UHF FM channel so that everyone can see and hear the combined channel. This FM downlink also eliminates the significant +/- 9 KHz Doppler of UHF on the PSK-31 signals, though it does require the ground station operator to re-tune his FM receiver a few times during the pass.



Full Duplex PSK-31 Operations: A very unusual design for this transponder is that the operators and users are operating full duplex on PSK-31. This way they can see their own signal withing the combined downlink just like everyone else. The station can then control the level of his uplink and see how it compares with others. Also, being full duplex, he can maintain as many as 30 simultaneous Conversations as fast as he can type. Think of it as a shared 2-way comm channel with everyone seeing everyone else in real time.

The Doppler at 28 MHz however is still present and over the duration of a pass, it can be as much as 600 Hz or at the center of the pass, as much as 6 Hz per second. Hopefully this Doppler rate change can be accommodated in the various PSK-31 DSP demodulators.

We have tried the PSK-31 transponder on 2 previous missions. In PCSAT-2 on the exterior of the ISS, the experiement was not turned on for several weeks, and then when it was, it only worked for a week or less. Uplink power level requirements increased to where even a kilowattt uplink could not be heard after a week. Post flight analysis indicated the problem. The HF uplink antenna was broken cleanly in half and was only held in place by the insulating Kapton tape. Without an uplink antenna, the experiment was useless. The other experiment was on RAFT. But RAFT suffered a separation anomaly and the HF antenna deployment was compromised.

We are calling this PSK-31 transponder a “propagation monitor” because we have chosen the uplink channel to be the center of the ten-meter PSK-31 activity to assure that there are lots of signals to monitor instead of a dedicated satellite uplink channel. This ten meter PSK-31 monitor system allows users to monitor these signals from above the ionosphere where propagation effects will be noticeable. The downlink from the satellite is in the UHF satellite segment on 435.275 MHz where the entire passband can be seen.



Ground Terminal Equipment for APRS: The world map above shows the typical downlink display as captured by PCSAT-1. These stations can be either fixed, mobile, or remote data sensors. But for mobile satellite operation, there are now a variety of fully integrated APRS radios as shown below. Shown left to right, first, in 1998 was the full duplex Kenwood D7 and then the D700. Then the DR-135 with add-on HamHUD or Argent Data systems TNC to give it an APRS display capability, and then in 2007 the fully capable D710 and recently the Yeasu VX-8R family and mobile FTM-350 (not shown). On the right are the two new HT's, the D72 and VX-8G both with built-in GPS! The D72 continues the D7 full duplex capability for full function hand portable Satellite Communications.



RADIO SETUP FOR SATELLITE OPERATION:

The D700/710 series radio has 5 independent system configuration memories so that you can easily switch between terrestrial and satellite operation with the press of a button. Typically the mobile operator will have one configuration for local commuting, another for the open road, another for mode J Satellites and another for Mode B satellites. These modes automatically configure the proper uplink and downlink band as well as configure the internal TNC to 1200 or 9600 baud and also for cross band operation.

Common APRS Settings: The common convention is to set your terrestrial callsign with an SSID of -7 for a handheld, and -9 for your mobile. For satellite operations use the SSID of -6. The reason to change the SSID is so that as your APRS data is received into the global APRS internet system (APRS-IS) those packets that went via the satellite will be separately logged compared to those via the terrestrial network.

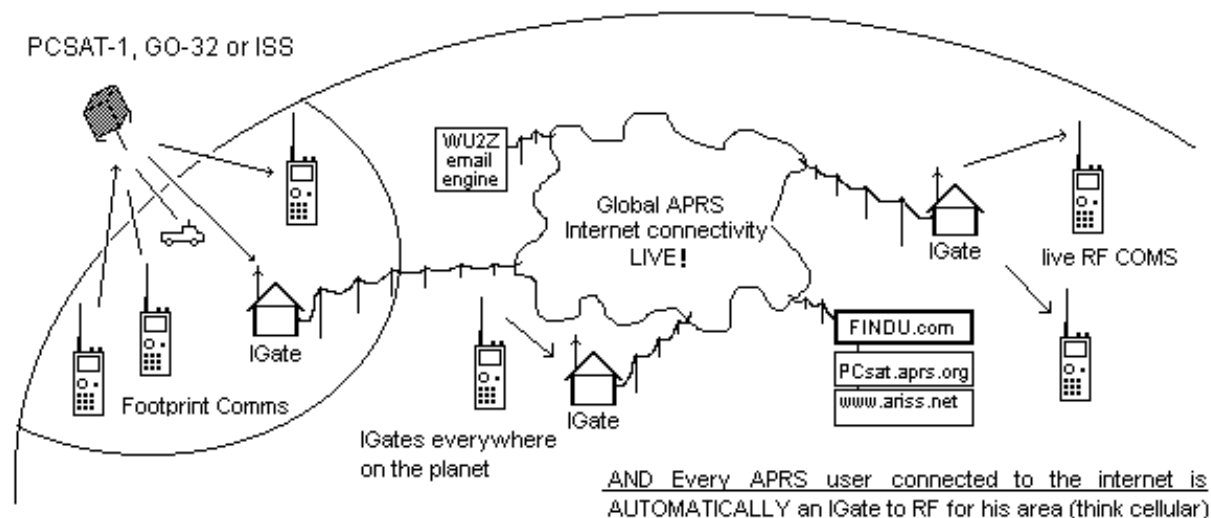
Most of the APRS menu items are self explanatory, but the most important setting not found in the APRS menu is under the RADIO-DISPLAY menu where you should set the DISPLAY-MODE to 3. This puts the APRS soft-keys on the front panel for rapid access to the APRS LIST and BEACON buttons which are the most useful to the APRS traveler and satellite operator. Without this setting, APRS functions are hidden from the front panel and are not as convenient as they should be. The D710 has a hot key to toggle between soft key menus without the press-and-hold function on the D700. There are numerous web pages with suggestions on setting up the various APRS radios for optimum APRS [4].

APRS Internet Gateway System:

Although APRS is a local information resource, it has global connectivity via the free bandwidth of the internet as shown in the figure below. The primary function of the Internet backbone is to allow the capture of all satellite packets for display and also for end-to-end messaging between any two users by simply knowing callsigns. All APRS packets go into the global channel and are available on-line, but only end-to-end messages come back out to RF for the intended recipient.

APRS Igate System

(End-to-End Everywhere)



GLOBAL REAL-TIME AND SATELLITE MESSAGING: Although APRS on RF is only a local or single satellite footprint system, it is globally connected via the IGate system for station-to-station messages. APRS has had local and global text messaging for 10 years. This is because all APRS messages transmitted anywhere all get captured into the APRS-Internet system (APRS-IS) by home stations or satgates linked to the internet. If any such Igate anywhere sees the recipient of your message in its local RF area, it will automatically pull that live message packet from the APRS-IS and send it in real time to RF to the targeted user. His system will generate an ACK and the ack will travel the reverse route to the sender in real time. This is not Email. These messages are live. If the recipient is not on the air, the message dies. No routing information is needed, just the sender and receiver callsign. If both stations are on the air anywhere in the Global APRS system, their packets get to each other without any prior routing or address knowledge required. Messages up to 45 characters show up nicely on the D7 display as shown in the next two figures.

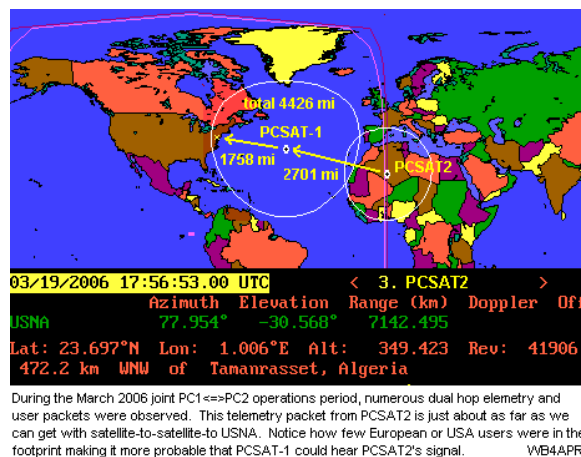
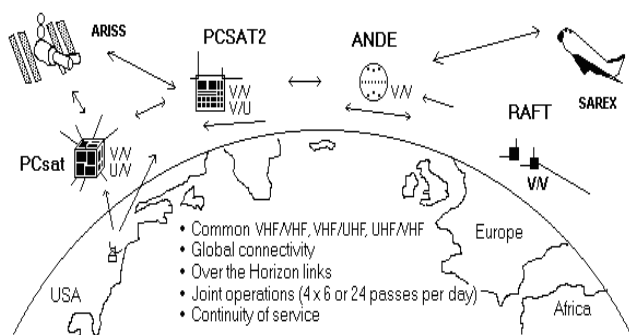
APRS messages are global and real time, as long as both stations are on the air. This message (below) is not to another callsign, but to the pseudo-callsign of Email. This special call will be captured by the APRS-IS and turned into a standard Email for delivery to the indicated recipient. This message was a test during a satellite pass.



EMAIL: In addition to live real-time global messaging, you can also use APRS to send one-line email to anyone from your mobile, complements of the APRS email Engine maintained by the Sproul Brothers, WU2Z and KB2ICI. Simply address your normal APRS message to “EMAIL” and enter the email address as the first word of the message line. Their WU2Z Email Engine at Rutgers University (see figure 11) will capture the message and wrap it up as normal email and send it to the internet. The Email engine will also send back a confirmation that the Email was sent.

This Email capability is the basis for APRS emergency messaging in disaster areas or for first responders. This capability (including via the APRS satellites) make it possible to send an email from almost anywhere in the world at least a few times a day. Recognizing the great potential for this system, all ham radio operators are encouraged to transmit a simulated emergency test message via any of the APRS satellites at least once a month to validate their abilities. See <http://aprs.org/sset.html>. [5]

GLOBAL APRS SATELLITE CONSTELLATION: All of the Naval Academy Satellites operated on the 145.825 packet radio satellite channel. This channel was pioneered by the DOVE satellite back in the Early 90's and has had a number of packet satellites since. As shown in figure 13, with all satellites operating on the same frequency (just like the terrestrial APRS system with all digipeaters operating generically on the same channel) the sum of all such satellites provide a continuum of support to mobile satellite operators.



All of the spacecraft operating on 145.825 provide a generic packet relay system and a continuation of coverage and availability. Not only does this provide better access, but it also permits dual hop

contacts as shown on the right. A packet from PCSAT-2 relayed by PCSAT-1 to our ground station in Maryland over a path of 4426 miles.

Most digital satellites and most of the Cubesats could support this APRS relay capability in their communications system designs. Even while performing their primary and scientific missions, these satellites could also relay occasional packets from users in view. With only 1 second per user, the power load on the satellite in this mode is miniscule. Even a cubesat power budget could handle a few additional 1 second packets per minute.

SATELLITE ALERTS: Not only are there several APRS satellite digipeaters in space, but there are numerous satellites that you can operate FM voice too while mobile with your FM rig [6]. The problem is that most of us are simply not aware of the dozen or so passes per day when we could be operating the satellites if we just knew they were in view. It turns out, your APRS radio or HAMhud display can instantly alert you and everyone else in your region any time an FM or APRS satellite comes into view. All it requires is someone in the area to set up a satellite-object server.

The satellite will appear like any other APRS object on the front panel of your radio showing you not only the callsign, name, location, distance and direction from you, but also it will show the frequency and even the current Doppler as shown below. In other words, everything you need to know on the front panel of your APRS radio. In addition, once every 10 minutes a satellite schedule is transmitted to your mobile for capture in the DX list to inform you of any satellites that may come into view in the next 80 minutes.

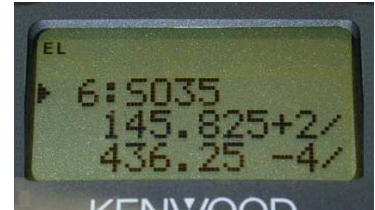
Over the years, dozens of AMSAT satellites could be worked from the mobile FM rig including SAREX, ARISS, SUNSAT, ECHO, UO-22, UO-23, PCSAT1, PCSAT2, SO-41, SO-50, ANDE, RAFT and GO-32. Unfortunately, at this writing, only ECHO, and sometimes ARISS and PCSAT-1 can be used reliably for packet and AO-50, and AO-51 (ECHO) for voice.

This figure of the D700 display shows the info distributed on the APRS channel locally when a satellite is in view. In this case it is the ISS. This info is updated once a minute if someone is running an APFRS satellite server in the area. The bearing and distance are shown and also the uplink and downlink frequencies plus range and Doppler.



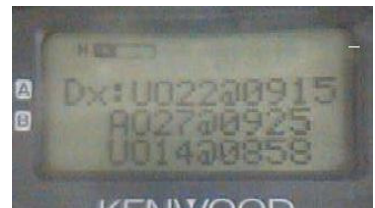
D-700 Front Panel Display of Satellite-in-view

Satellite Server: Satellite Alerts are only visible if someone in your region is running an APRS data resource server such as the old DOS APRSdata.EXE, or the UIview add-on called InfoKiosk, or the software called DIGI_NED. These programs run automomously at someone's shack keeping track of all the Amateur Satellites of use to mobiles in an area. If anyone of them comes above the horizon in that area, the software begins generating 1 minute updates to an APRS object and transmitting this object out on the APRS channel to all stations. These objects will appear on the front panel of everyone's APRS radio or HamHUD display. On the D7 walkie-talkie display, the information is easier to see at a glance as shown in the following figures.



In-view Satellite data on the D7 screen shows the satellite name and operating frequencies and present Doppler. Other displays on the D7 show the direction and distance.

A special satellite schedule packet is transmitted every 10 minutes to update this display in the D7's and D700's DX list. It can show up to four of the upcoming satellite passes expected in the local area. This one showed the times of the next UO22, AO27 and UO14 satellites.

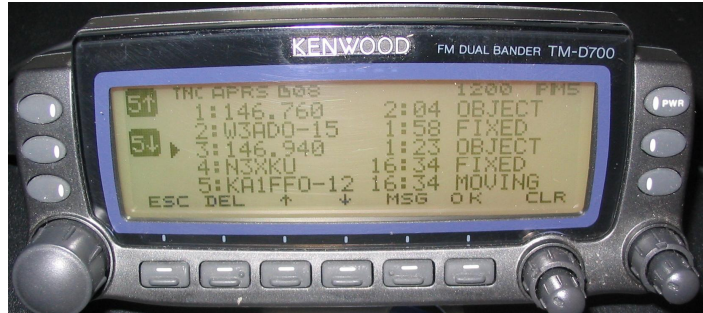


Terrestrial Use between passes... A National Calling Channel and Voice Alert: Although an APRS channel is wall-to-wall with packets, probably 99% of them have been relayed by a digipeater. All of these repeated packets do not have any CTCSS tone with them so the speaker can be muted by simply setting CTCSS 100 tone squelch. But, to distinguish LOCAL simplex range packets from digipeated packets, the original senders of APRS data can include a 100 Hz CTCSS tone. This is so that simple monitoring of the channel with the speaker muted by CTCSS 100 will allow for practically silent operation while still providing an audio alert if another operator is nearby and comes within simplex range. This is a very powerful APRS mobile feature called Voice Alert. Using CTCSS 100 anyone can contact such an APRS operator by voice by simply making the call on the APRS channel with tone 100 if needed [7]

Operating Frequency Identification: The most significant new initiative in terrestrial APRS is the addition of the frequency field to the packet data. This allows APRS operators to show the voice frequency they are monitoring with their dual band radio. Adding this frequency field in everyone's position packets that show up on the front panel of APRS radios or heads-up displays (HAMHUD) adds a new dimension in communication capability. The D710 display list (below) was sorted by callsign and stations AB9FX were reporting their monitoring frequencies. Clicking on any of these stations will reveal 3 more pages of info on that station, or you can just press TUNE button and the D710 will instantly tune to that channel and tone.



Recommended Voice Frequencies Everywhere: But there are lots of other frequency objects on APRS. To assist the mobile satellite operator and traveler, the APRS network now transmits locally recommended voice repeater frequencies in each local area [8]. You can see three of these in the figure above. These local repeater objects show the Frequency right on the front panel list and when selected, even include the Tone, Net times, and meeting dates as well. When you see one of these, you can just push the D710 TUNE or FTM-350 QSY button to tune directly to them. An additional feature is the new List SORT button which can SORT the list alphabetically or by range making it easy to find others. The display above is after an alphabetic sort so that all the Frequency objects show up at the top of the list.



By using the recommended local voice repeater frequency as an APRS object name, these recommendations show up for the mobile traveler whenever he enters a new area. The D700 above shows the most recently received 146.76 is in direct range. The older 146.94 has moved down the list since it was heard 35 minutes earlier.



Echolink and IRLP Node Frequency Objects: Other frequencies of immediate local interest to the mobile traveler are the EchoLink nodes, IRLP nodes and Winlink Telpac stations. Echolink and IRLP nodes are displayed on the APRS radio's list as node numbers instead of callsigns to facilitate ease of use by mobiles as shown in figure 6 and include their Frequency, Tone, Range and Status (Rdy, Bsy, Lnk). This will be useful when APRS and Echolink and IRLP are merged into the automatic Voice Relay System AVRS [9]. Two example screens of these objects are shown below.



GPS Map Displays:

Not only do the APRS radios and Head's Up displays give you textual information, any attached GPS with a map display can also display the surrounding APRS symbols of all the other APRS stations and objects in the area! The GPS map will show all surrounding APRS stations, mobiles, weather stations, and objects, right there on the GPS even those you receive via satellite. With a good GPS with built-in maps, no laptop is needed in most APRS mobiles. Recently, the AVMAP G5 even includes the full APRS symbol set so these other stations appear on the GPS map with full color symbols as shown to the right. The smaller Garmin NUVI-350 can also display multiple APRS symbols via a special interface dongle made by Argent Data Sysyems (though the NUVI-350 is no longer in production).



Flash-up Instant Information Display

While monitoring the satellite downlink or national APRS terrestrial channel, each new incoming packet with new information flashes on the radio or HamHud screen for 10 seconds or so as shown in the following figure. In this way you are instantly alerted to anything new in range without your hands ever leaving the steering wheel. This display is useful for conveying to



travelers the location and frequency/tone of the local calling frequency as well as all other assets or satellites in view. A new feature of the D710 is that the Display Head can be used as a stand-alone APRS display when hooked to the audio connections of any radio. This is useful when removed from the mobile and maybe carried inside to the club or EOC and operated with any HT.

This D700 display shows how the left side of the radio flashes each new packet momentarily. It shows why we like to concentrate information into the first 20 or 28 bytes of a packet so that it displays well on the 10x10 display of the D7 and the 10x10x8 display of the D700 shown here. Here we see the local repeater, its tone, its typical range, and its weekly net times all in one packet.

CONCLUSION: Many of us only have time to really enjoy ham radio while we are mobile. The purpose of this article is to make sure everyone is aware of the vast potential for mobile satellite operation if we just know when a satellite is in view. This information as well as a wealth of other information should be made available to the mobile operator on his front panel screen. Due to limited space, only a few of the dozens of display screens and data formats could be shown in this article. Think of these APRS mobile displays as Tiny Web Pages of Local Live information [10] everywhere you go. Compared to cell phones, the big advantage of ham radio is it's one-to-many access to information. But just like a dead-band, there is only information to receive if someone else is transmitting it.

So think outside the box. APRS has been available as this local information resource for over 15 years, but many operators are still not taking advantage of this valuable local and global resource. Think about what info you can put out in your own immediate simplex range neighborhood that would be useful to the traveler or visitor. But be considerate. One area's local information, if received somewhere else, is SPAM! For everything about APRS, see <http://aprs.org> [11].

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- [3] Parkinsonsat web page: <http://aprs.org/psat.html>
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- [5] APRS Emergency Tests: <http://aprs.org/sset.html>
- [6] APRS Satellites: <http://aprs.org/astars.html>
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A lightweight 20 foot stressed dish for 1296 MHz EME

Marc Franco, N2UO

This article was originally published in the Proceedings of the 14th International Earth-Moon-Earth Conference, held in Dallas, Texas, in August 2010. The EME Conference Organizing Committee kindly gave AMSAT permission to reuse the material.

Although this work describes a parabolic reflector maybe too large for use by the average AMSAT member, the ideas can be employed to construct very lightweight, inexpensive parabolic reflectors of smaller size. In fact, the author used for several years a 10' reflector built following the techniques described below for AO40 L/S operation and 1296 MHz EME.

Introduction

Building a large dish for 1296 MHz EME can be a complex and expensive project. Every time the diameter is doubled, 6 dB of additional gain can be obtained, but the dish area and weight are actually quadrupled.

After using a 10' stressed dish for about 9 years, I decided that it was time to build a larger antenna, settling for a 20' dish with similar characteristics and construction style as the 10 foot antenna.

Design criteria

Stressed dishes were made popular by Al Katz K2UYH and Dick Knadle K2RIW [1] [2] [3]. Many EME operators have built them and used them for long periods of time, usually until the antennas were destroyed by a powerful storm. The basic principle of stressed dishes relies on the approximation of the parabolic shape by pulling the ends of the spokes with ropes, wires or strings. For small and shallow dishes (10' and f/d 0.5), the method works quite well. However, for larger diameters and deeper reflectors, the surface error increases significantly, leading to a loss of gain [4]. One way to overcome this problem is to pre-bend the spokes so that their shape will not be totally determined by the pulling force of the strings. This method worked out very well on the 10 foot antenna, so I decided to apply it again.

Most EME operators keep their dishes pointing up when not in use to minimize wind load. A 20' stressed dish is a large structure and would have to be mounted at least 10' high. This doesn't look like something that will survive strong winds, so I realized that I needed to do something different if I wanted to use the dish for several years. I had to devise a way to bring the dish as close as possible to the ground, and tie it down with several ropes. This is much easier said than done when a large structure is involved.

Mount construction

I started the project by designing the mount. I used a Rohn 25 flat top cap 8' tower section (25AG4) with a 3 inch weatherproof thrust bearing at the top, and a hinged base (R-BPH25G), so the tower could be raised to the vertical position during operation, but kept almost horizontal and close to the ground when the dish is not in use (Fig. 1). I bought all the tower hardware at a heavily discounted price from fellow hams and at various hamfests. I found a prop-pitch motor circa 1945 at the right price for the azimuth control, and my neighbor donated a 24" linear actuator for the elevation from his old TVRO dish.

I built two OE5JFL-style 10-bit optical encoders [5] for positioning control. It took quite an effort to get them to work properly, but the cost of the parts was only a fraction of the cost of a commercial unit. The elevation encoder relies on a weight attached to its shaft for reading the elevation, and the azimuth encoder is coupled to the dish support pipe with 2 sprockets obtained by splitting in half the main sprocket of a lightweight winch that I purchased at a hamfest. The azimuth mechanism is shown in detail in Fig. 2 and Fig. 3.

The antenna movements are controlled by an auto-tracker designed by OE5JFL [6]. The relays, power supplies and remote tracking unit are all housed in a weatherproof metal enclosure mounted on the tower section, as shown in Fig. 4. The prop-pitch motor runs off 5 V dc for very low speed (nominal 28 V), and the elevation operates with 18 V dc instead of its typical 24 V.



Fig. 1 – The antenna is kept close to the ground at 90 degree elevation when not in use. Note the support structure to relief winch stress.

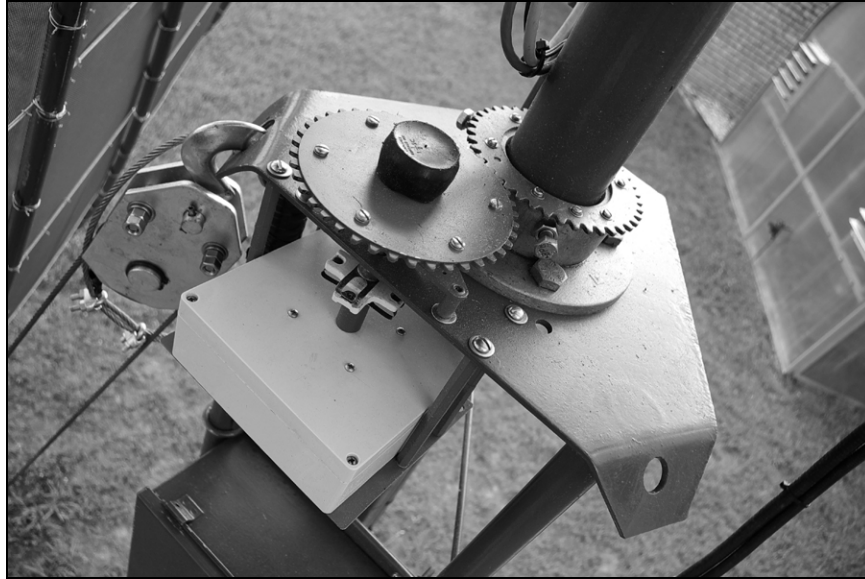


Fig.2 – Azimuth optical sensor (large white box) coupled to the main support pipe by means of two sprockets. Note the heavy duty pulley for raising the tower.



Fig. 3 – Prop pitch motor used for the azimuth rotation.

The dish is mounted on a surplus TVRO polar mount converted to azimuth-elevation. I added a frame made with 2"x4" wood to increase the distance between the mount and the reflector in order to clear the tower section at low elevation (Fig. 5).

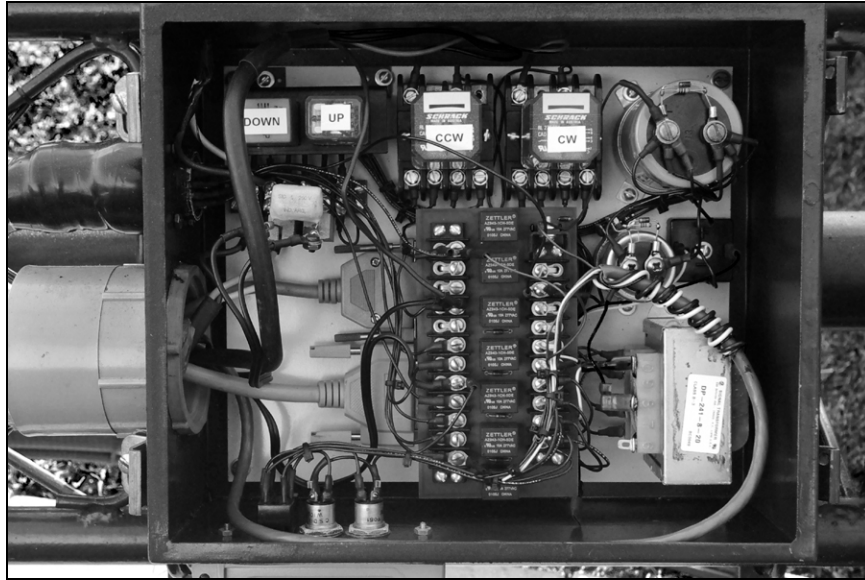


Fig. 4 – Outdoor control box and associated electronics.



Fig. 5 – Hub and elevation actuator. The small white box is the optical elevation sensor.

Reflector structure design and construction

The stressed dish structure consists of 20 spokes attached to a 2' center disk. The spokes are 10' long aluminum conduit used for electrical installations [7]. Their cost is higher than regular aluminum tubing for antenna construction. However, shipping by truck 10' long pieces can easily double the total cost of the material, so I opted for the electrical conduit that I could pick up myself. The conduit comes with an end coupler to attach two pieces together, which comes really handy since it provides extra strength at the ends.

The spokes must be pre-bent in order to accurately follow the parabolic curve once they are installed and pulled by the ropes. This process can take considerable time if it is done by hand, like I did. First, it is recommended to cut a template of the dish's profile to use throughout the reflector construction. I used a large piece of Styrofoam home insulation for the template, which I had to join since they come in 8' long pieces. The Styrofoam is about 1" thick and very light, so it can be handled quite easily.

In order to find out the exact shape at which the spokes had to be pre-bent, I attached one of them to a vise like if the spoke were attached to the dish hub, and then pulled the end to match the template's shape in the best possible way. I then bent the spoke in small amounts to minimize the error throughout its length. Once I was satisfied with the first spoke's shape, I used it as a template to bend the rest of them.

The center hub consists of a 2' diameter disk and a 2x2 feet plate made of 1/4" thick aluminum. The spokes are sandwiched between the disk and the plate. The whole structure is held together with #8 stainless steel screws and nuts (Fig. 6).



Fig. 6 – Details of the hub, showing the two aluminum plates and part of the feed support structure.

The spokes are pulled from their ends by $\frac{3}{32}$ " UV-resistant Dacron double weave rope. Phillystran could be used for more reliable performance, but at a much higher cost. One end of the rope is attached to the spokes with a small size turnbuckle for minor surface adjustments, while the opposite end is attached to a 3' long aluminum tubing 2 $\frac{1}{4}$ " in diameter mounted at the center of the hub, which also serves as part of the feed support. Fig. 7 and Fig. 8 show details of the construction.



Fig. 7 – 20 Dacron ropes are attached to the feed support to pull the end of the spokes.



Fig. 8 – Detail of the attachment of the rope to the spokes and outer ring.

After the spokes and the ropes are installed and adjusted, a wire ring must be installed to form the rim of the dish. The easiest way to do this is to drill through the couplings that come with the electrical conduit and run a galvanized fencing wire ring around the dish. I actually ended up running two rings for additional strength. I later replaced these rings with a single ring made of ½" aluminum tubing, as it can be seen in Fig. 8. The aluminum was purchased in 6' sections that were joined together with 3/8" tubes. The ring was preformed using a homemade pipe bender made with 3 plastic pulleys. Unlike the spokes, the ring does not have to be bent too precisely.

Reflector surface construction

The material for the reflector surface must be lightweight, inexpensive, and able to maintain its shape between the spokes. Unfortunately, it is very difficult to meet all those requirements at once.

Galvanized hardware cloth is too heavy to be used on a large stressed dish. Aluminum expanded metal can be made to order and the opening size and sheet gauge can be selected for optimum RF leakage and weight. Unfortunately, its cost is beyond most budgets.

The last choice I considered was regular aluminum window screening. It is by far the lowest cost and lighter weight, but it is hard to maintain its shape between the spokes due to its lack of rigidity. The opening is so small that leakage would not be a problem.

Aluminum window screening requires additional support between the spokes in order to maintain the shape. For that purpose, I installed 7 additional fencing wire rings. The first two are at 9" intervals, the following 4 rings at 18" distance from each other, and the last ring again at 9" from the previous one. The rings can be seen in Fig. 9.

One problem I found after installing the rings was that I would actually need to attach the mesh at intervals closer than the distance between the rings. Unfortunately, those attachment points would not be leveled with the rings. I realized that by cutting short pieces of ¾" plastic electrical conduit and then cutting those pieces in half into a "U" shape, they would snap onto the aluminum spokes very nicely, and they would provide almost the additional height needed to level the mesh. See Fig. 10 for details.

I purchased a 100' long by 4' wide roll of charcoal aluminum screening. I cut ten 10' long pieces, and then I cut them in half in an angle, starting 5" from one end, and finishing 5" from the opposite end, as shown in Fig. 11. I mounted the 20 screen pieces on the dish using hundreds of small pieces of aluminum MIG wire, and trimmed the edges as necessary. The pieces of screen overlap a few inches to minimize RF leakage. I normally start by attaching the mesh to the center of the dish, then I attach the opposite end to the outer ring, making sure the mesh is stressed, and finally I install the rest of the wires. Fig. 12 shows details of the mesh installation.



Fig. 9 – View from the back of the dish, highlighting the mesh support wire rings and counterweights.

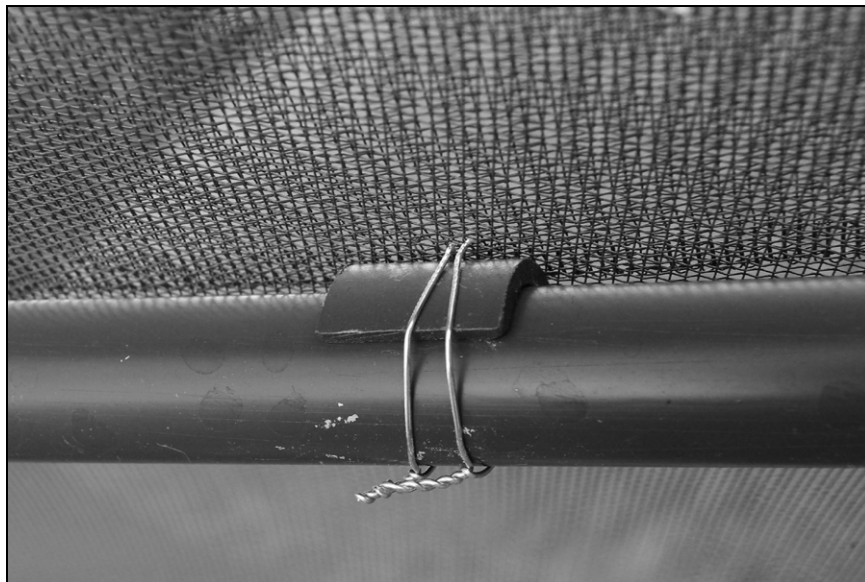


Fig. 10 – Plastic snap-on piece to provide additional attachment points for the mesh.

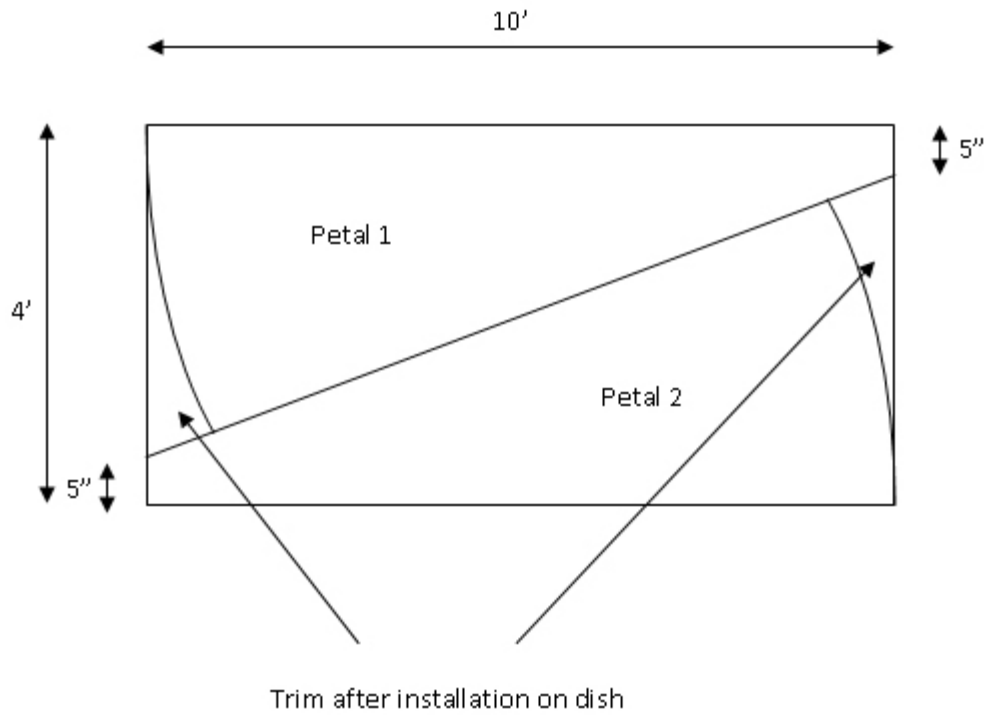


Fig. 11 – A 10' long piece of aluminum window screening can provide 2 petals if cut as shown.

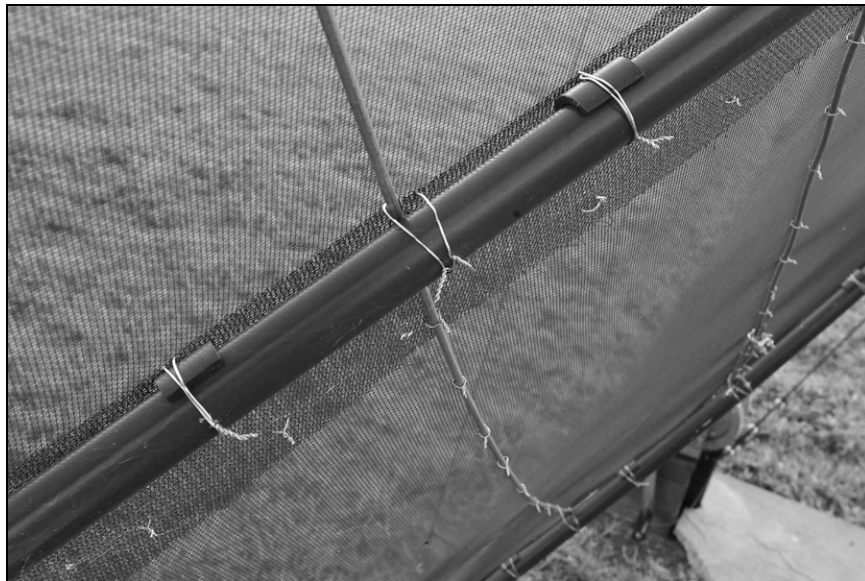


Fig. 12 – View of the mesh attachment method using aluminum MIG wire.

Feed support

The feed support details are shown in Fig. 13. I used a combination of aluminum tubing and 2" copper elbows used for water installations. All tubes had slits cut at their ends and the various pieces are held together by several stainless steel hose clamps.

The feed is held in place by two supports made with 1 1/2" diameter aluminum tubing and two pieces of wood covered with weather seal ribbon material to smooth out the surface and prevent damage to the feed. There is an additional support that holds the larger diameter part of the feedhorn and prevents misalignment.

The feedhorn and the outdoor electronics are mounted at more than 10' away from the hub. In order to help support this significant weight and prevent feed misalignment at different elevation angles, two steel cables are run between the feedhorn and the counterweight structure. In addition, four ropes stretch from the feedhorn to the rim of the dish to provide additional support when the antenna is at 90 degree elevation.



Fig. 13 – View of the feedhorn and support structure.

Counterweight and raising mechanism

Such a lightweight but large dish is not likely to survive strong winds if it is up in the air, even if it is facing up to minimize wind load. In addition, a 20' dish is a significantly large structure and for various reasons one might want to keep it out of sight when not in use, which happens to be approximately 96 % of the time for regular EME operation (one

weekend a month for a few hours). This could be accomplished by lowering the dish as close as possible to the ground and holding it down with several ropes.

Since the support tower in this design is fitted with a hinged base, it should be possible to tilt the tower down using a winch. However, there are two problems with this approach. First, the force required when the tower is close to the ground would be very strong if the winch is mounted on the ground, and second, the counterweights would hit the ground, limiting how much the tower could be lowered.

I managed to solve both problems at once by using a very simple approach. The counterweights consist of two blocks of concrete each, mounted at one end of a 2x4 inch piece of wood, while the opposite end of the wooden support is attached to the dish hub with a $\frac{1}{2}$ " galvanized bolt, loose enough to allow the wooden support to rotate (see Fig. 5). This allows the counterweight to move up and down, but not sideways. A steel cable is used to support the counterweights when the dish is in operation, allowing them to always be at ninety degrees with respect to the hub. The far end of the counterweights is fitted with casters, so when the dish is lowered to its resting position, the casters hit the ground and the counterweights fold over, permitting the dish to be lowered very closely to the ground. At the same time, since the counterweights are resting on the ground when the tower is lowered, the winch no longer supports their weight. Fig. 14 shows the dish being raised to its operating position at the point when the counterweights are about to lift off the ground.



Fig. 14 – Antenna being raised to the operating position. The counterweights are about to lift off the ground.

Conclusion

The finished antenna is shown in Fig. 15. It has already been used for several months with great success. It survived several storms without damage, and the raising mechanism has worked flawlessly. The antenna is fed by a dual-mode feedhorn with a 5-step septum polarizer [8].

Snow seems to be its worst enemy so far. We had several inches of snow this past winter, and after an inch or two I quickly noticed that the weight was in excess to what the structure could support. Since the dish is normally stored looking up and would become a snow collector, I resorted to spread some rock salt on it before it started to snow, which did not allow snow to accumulate. Since rock salt can corrode metallic parts, the dish must be thoroughly cleaned afterwards.

A stressed dish is probably the least expensive construction method to build a high gain antenna for 1296 MHz EME. Most of the materials used were purchased locally at hardware stores. Moreover, the antenna is light enough to be mounted on a tilt tower to keep it close to the ground when not in use.



Fig. 15 – View of the antenna in the operating position.

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100W VHF / UHF Amplifier Design and Construction

Stephen D. Turner, PE

k3hpa@amsat.org

k3hpa@arrl.net

Background

The objective of this amplifier project was to provide a 100W linear amplifier that could be driven by the Yaesu FT-736R for FO-20, FO-29, and AO-10 satellite operation. A good 100W amplifier is very useful for reliable satellite communications, particularly with the older AO-10. This paper presents the design and construction of such a 100W VHF amplifier and a 100W UHF amplifier that is useful for amateur radio applications and easy to construct. The amplifier is versatile in that it can be used for amateur satellite SSB operation as well as terrestrial FM. The amplifier has sufficient gain so that it can be driven by a wide variety of transceivers from 5W HT's to 10W-20W rigs such as the Yaesu FT-736R. Appropriate control circuitry is included which allows the amplifier to be remotely controlled by a microcontroller or personal computer.

RF Device Selection

There are a wide variety of RF transistors that can be used in the VHF-UHF region at the 100W power level. These include bipolar transistors, MOSFETs, GaN HEMTs, and SiC FETs. The FET family of devices are quite popular in many commercial amplifiers due to their high gain and low distortion properties. However these devices are often out of the price range of the amateur radio experimenter and can be difficult to obtain in small quantity. For this reason it was decided to utilize bipolar transistors developed for mobile radio service. These devices are available from many sources such as RF PartsTM Company, www.rfparts.com. The device used in the VHF amplifier is the MRF-247 (2SC2782). This is a 70W VHF mobile radio transistor. The UHF amplifier uses the MRF-648 or MRF-650 device. These are 60W silicon NPN mobile radio transistors. Another subtle advantage of using bipolar devices is the lower operating voltage. The bipolar devices used in this amplifier are optimized to operate from a +12 VDC to +14VDC collector-emitter voltage. This makes them ideal for mobile operation using the +12VDC automobile battery without the need for voltage boost converters.

RF Power Amplifier Design

The schematic of a single MRF247 amplifier stage is shown in Fig. 1. Each stage of the amplifier is built on an individual carrier to facilitate the assembly and test of each individual section of the amplifier. The carrier can be an aluminum or copper block to which the RF substrate is soldered. A pocket is machined so that the flange mount transistor's leads line up with the RF substrate. The carrier assembly of a MRF247 stage is shown in Fig. 2. The carriers are then bolted to a common heat sink plate using thermal grease. As the schematic shows, an open loop active bias circuit is used to control the quiescent current through the RF transistor. This circuit provides a constant current source for the base of the transistor with some temperature compensation provided by the 2N3904 mounted directly on the carrier. The potentiometer in the emitter of the 2N3904 is carefully adjusted to achieve the desired collector current in the RF

device. The collector current is measured by measuring the voltage across the $0.01\ \Omega$ sense resistor in the collector circuit. Because this amplifier is used for SSB and FM applications, the collector current is set to about 2 Amps to achieve a good class AB bias condition. VK200 Inductors are used to supply the base and collector bias to the RF device. A PI type matching network is used to make the amplifier easy to tune over the entire two meter band.

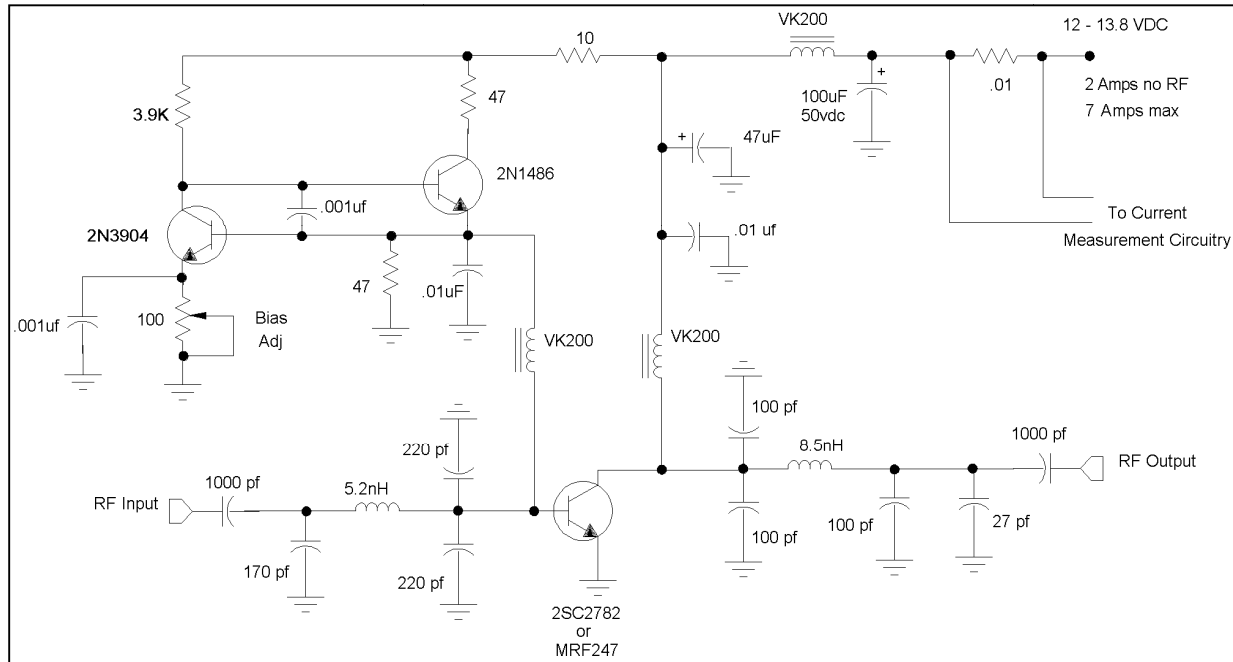


Figure 1. MRF247 Single Stage Amplifier Carrier Schematic including Bias Circuitry

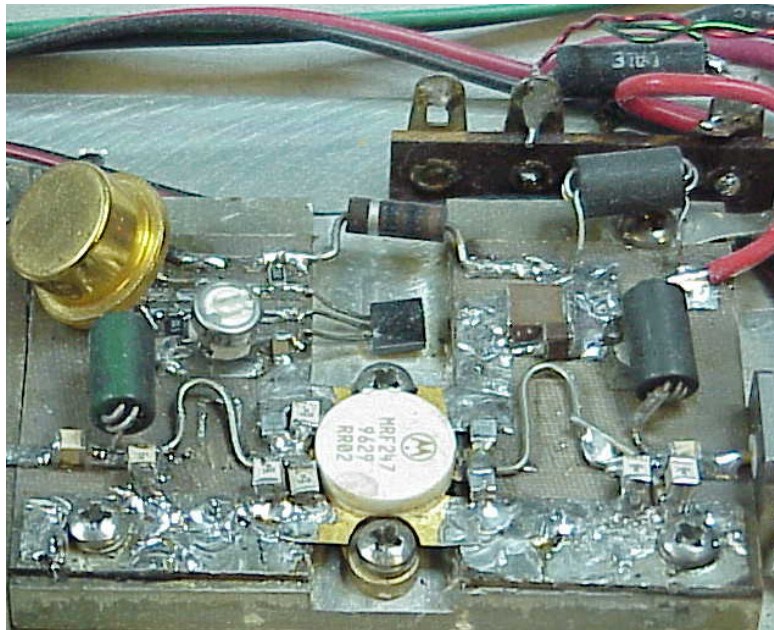


Figure 2. MRF247 Single Stage Amplifier Carrier Assembly (base on left; collector on right)

The MRF648 UHF stage is also built on a carrier. As the schematic of Fig. 3 shows, the same bias circuitry is utilized as well. Only the RF input and output matching elements differ. From Fig. 4 note that the small inductance values are realized by a short length of AWG#18 silver plated wire. The shunt capacitors in the matching networks are 200v, 0.110 x 0.110 case size multilayer chip capacitors.

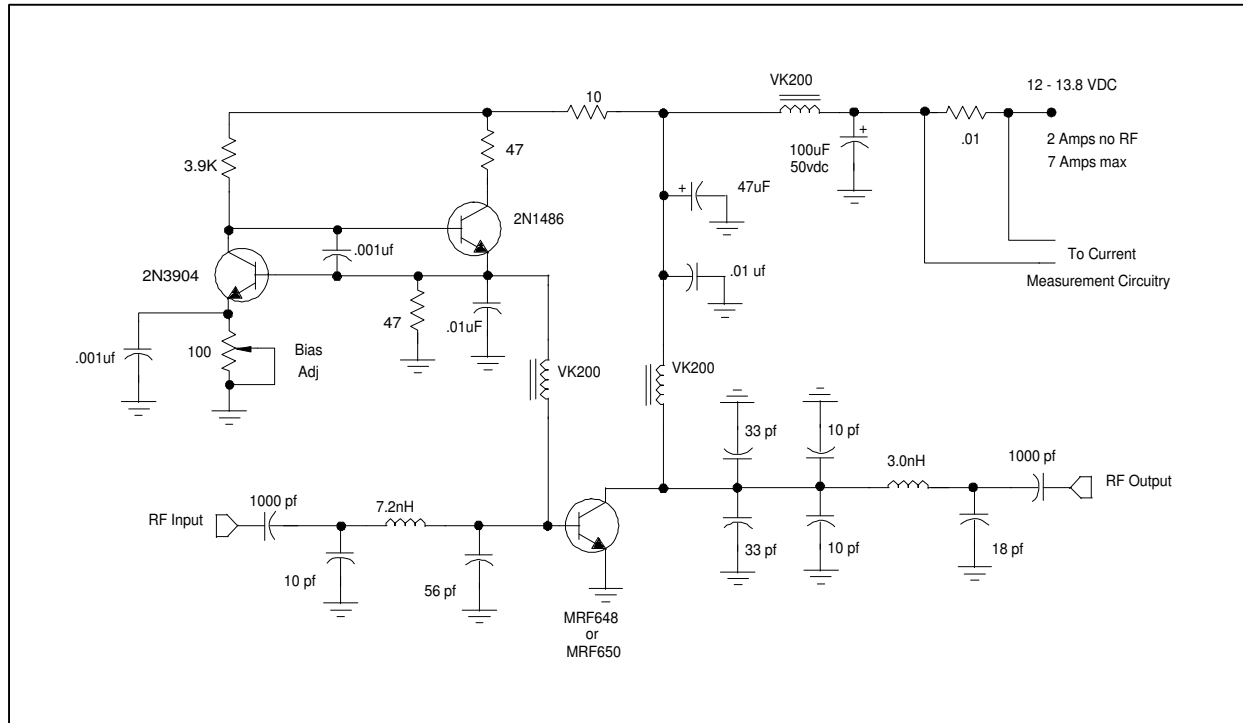


Figure 3. MRF648 Single Stage Carrier Schematic

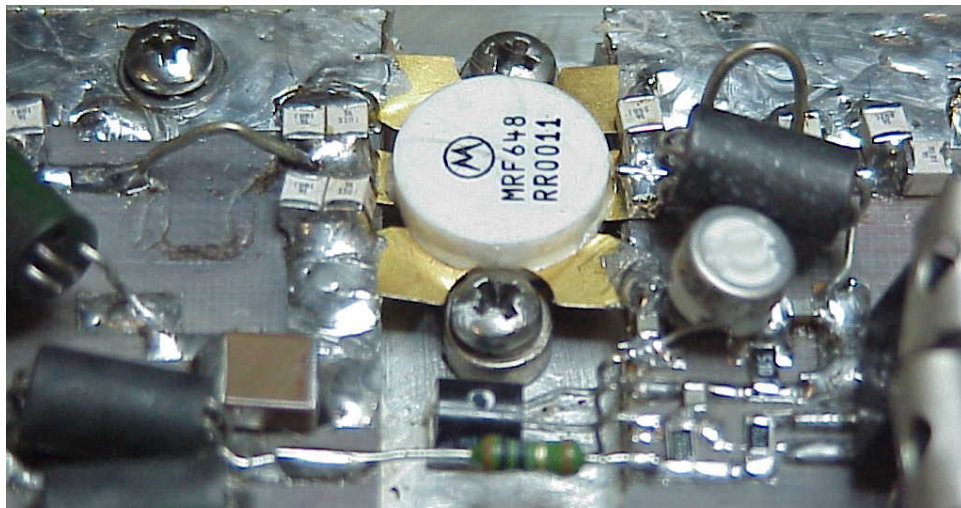


Figure 4. MRF648 Single Stage Carrier Assembly (collector on left; base on right)

To obtain 100W output power from each amplifier, two devices will be ‘phase combined’ by means of a splitter-combiner combination. One characteristic of the bipolar device is that it has much lower gain than an FET. Therefore to operate with low power (5W-20W) transceivers a two stage cascaded amplifier is required. The basic RF block diagram of the amplifier is shown in Fig. 5. The resulting amplifier is a two-stage, three device power amplifier. The power splitter and combiner circuit is a reciprocal device in that the same circuit can be used on the input and output.

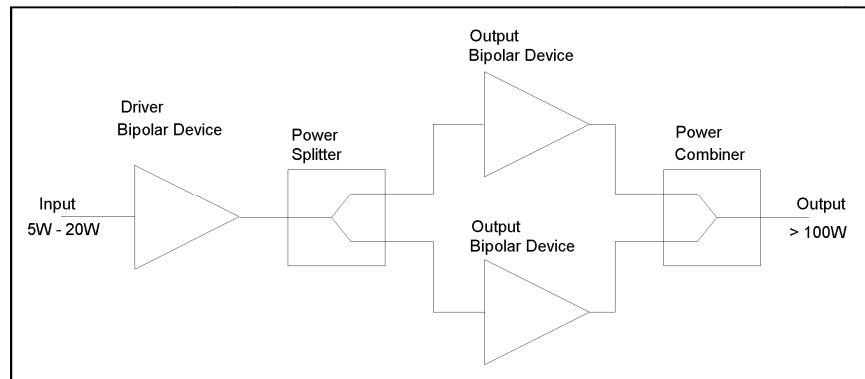


Figure 5. Basic RF Block Diagram of Each Power Amplifier

There are a multitude of splitter and combiner designs that can be used in power amplifier design. For the VHF amplifier, an in-phase, lumped element, Wilkinson style power splitter has been implemented. This splitter is attractive at lower frequencies as the lumped elements (discrete inductors and capacitors) significantly reduce the size of the splitter. The lumped elements have lower losses at the VHF frequencies making them an efficient power combining network up through a few hundred watts. Fig. 6 shows the MRF247 output stages connected between a lumped element Wilkinson splitter-combiner network. The component values of the splitter are shown in Fig. 9.

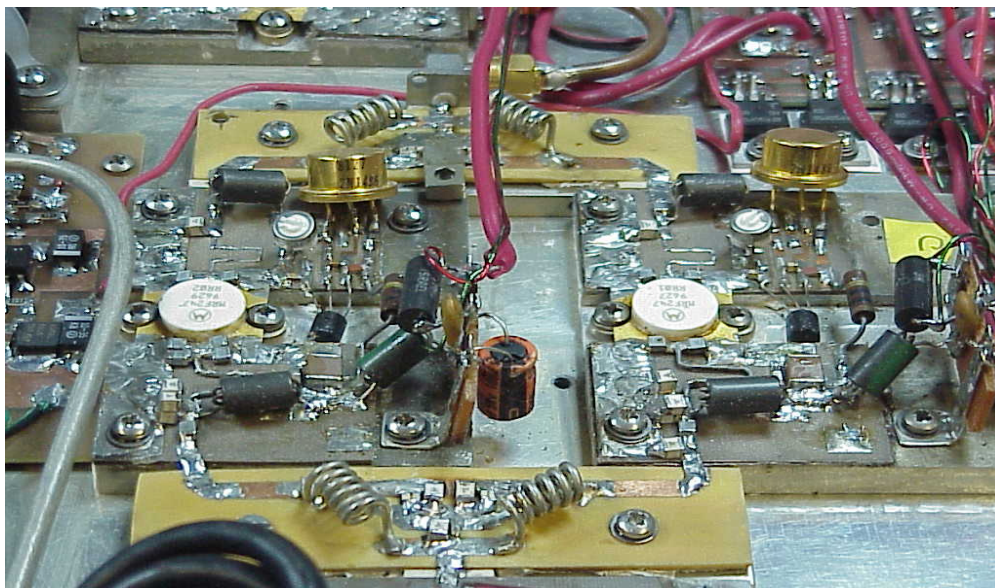


Figure 6. MRF247 Output Stages with Lumped Element Splitter/Combiner Networks.

To preserve as much power as possible at UHF a more efficient splitter-combiner network is required than what could be achieved with the lumped element Wilkinson approach. A good low loss, small size combiner in the UHF through S Band frequency range is Wireline. Wireline is manufactured by Sage Laboratories <http://www.sagelabs.com>. Wireline is a phase quadrature coupling structure that is realized by two parallel coupled lines in a coaxial transmission medium. The 'J' series Wireline looks very similar to 0.141 semi-rigid cable but with two inner conductors. One inner conductor has a Kapton insulation to provide DC insulation between the two conductors. For 400MHz operation, a 4 inch length of Wireline is required to make a 3dB hybrid coupler. Due to the coaxial cable realization the Wireline is easy to bend and form into various shapes. By forming a loop with the Wireline the MRF648 output stages can be spaced 2 inches apart rather than the full 4 inch length of the Wireline. This is shown in the output device carrier of Fig. 7. Because the Wireline is a four port hybrid coupler, a 90 degree phase shift exists at the splitter outputs. The fourth port must be terminated by a 50 Ω RF termination style resistor.

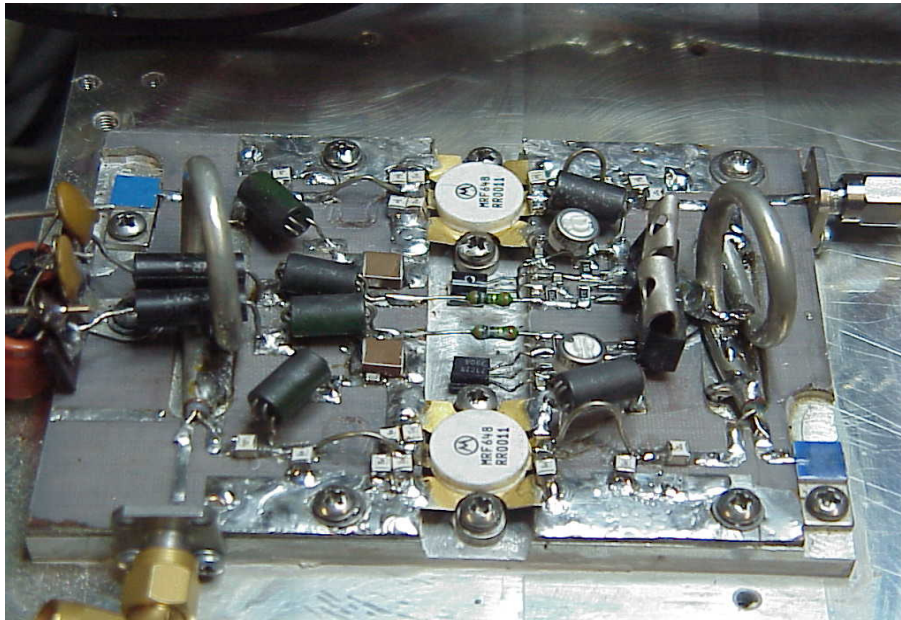


Figure 7. MRF648 Output Stages with Sage Wireline Splitter/Combiner Networks

T/R Switching

The Transmit/Receive, T/R, switch is an essential part of the amplifier for use with a radio transceiver. It essentially provides a means of bypassing the power amplifier and providing a low loss path for the receive signal to arrive at the transceiver. The T/R switch is realized as a pair of ganged single pole-double throw switches on each side of the amplifier as shown in Figure 8. The actual switch can be realized in many forms including mechanical relays and transfer switches as well as electronic switching. Electronic switching is typically achieved with PIN diodes. In this amplifier project the UM9401 PIN diode is used in the VHF amplifier and coaxial relays in the UHF amplifier. As the schematics of Fig. 9 and 11 show, the same control circuitry can be used with both the electronic and mechanical switch with minor modification. A 555 timer is used as a one-shot to provide some delay for the T/R switch in the 'key-up' condition. To increase the versatility of the power amplifier there are two ways of engaging the T/R switch. One way is to sample the incoming RF by means of a peak detector diode. This is convenient for FM operation in that no additional hardware interface is required between the transceiver and the power amplifier. Because the FM carrier has constant amplitude, the T/R switch remains

engaged as long as the input RF signal is present. For SSB operation however, the incoming RF amplitude is changing with the modulation. Thus the peak detector circuit cannot be used. For SSB operation, the Linear Amplifier control lines which most SSB transceivers have are used to engage the T/R switch. The Linear Amplifier control line is typically a relay or open collector stage which is pulled to ground during key-down.

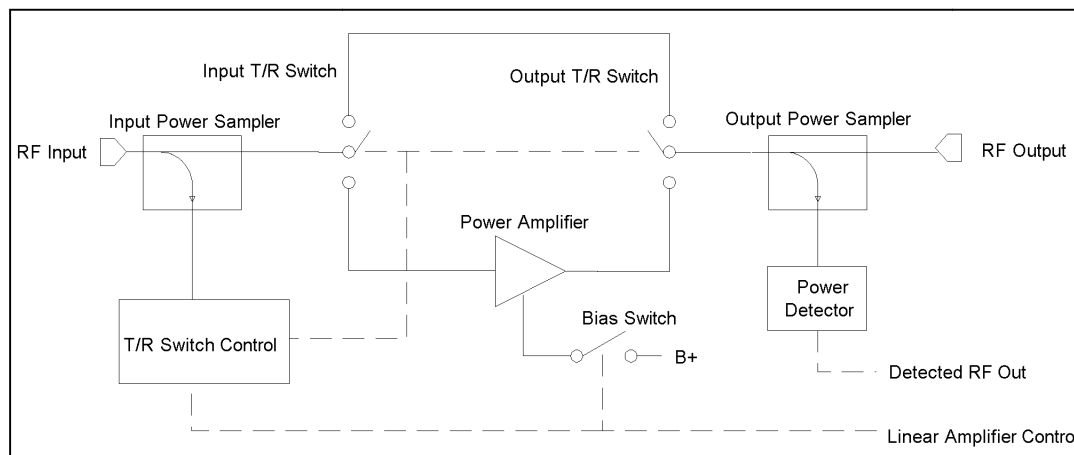


Figure 8. Functional Block Diagram of Power Amplifier

Each PIN diode SPST switch consists of a series diode and shunt diode with a quarter wave transmission line spacing. When both diodes are forward biased they provide a very low resistance (RF short circuit). The shunt diode then provides a good RF short in which one quarter wavelength away, appears as a good RF open. In the transmit state, the diodes are forward biased in which the series diode connects the amplifier to the transceiver and the antenna. In the zero bias (receive) condition the PIN diode has a very high resistance. Thus the series diode blocks the RF signal from the amplifier while the shunt diode allows RF to pass with low insertion loss. The quarter wave transmission line is realized by an 11 inch length of RG-58U that is wound in a small coil as shown in Fig. 10. To reduce the insertion loss in the

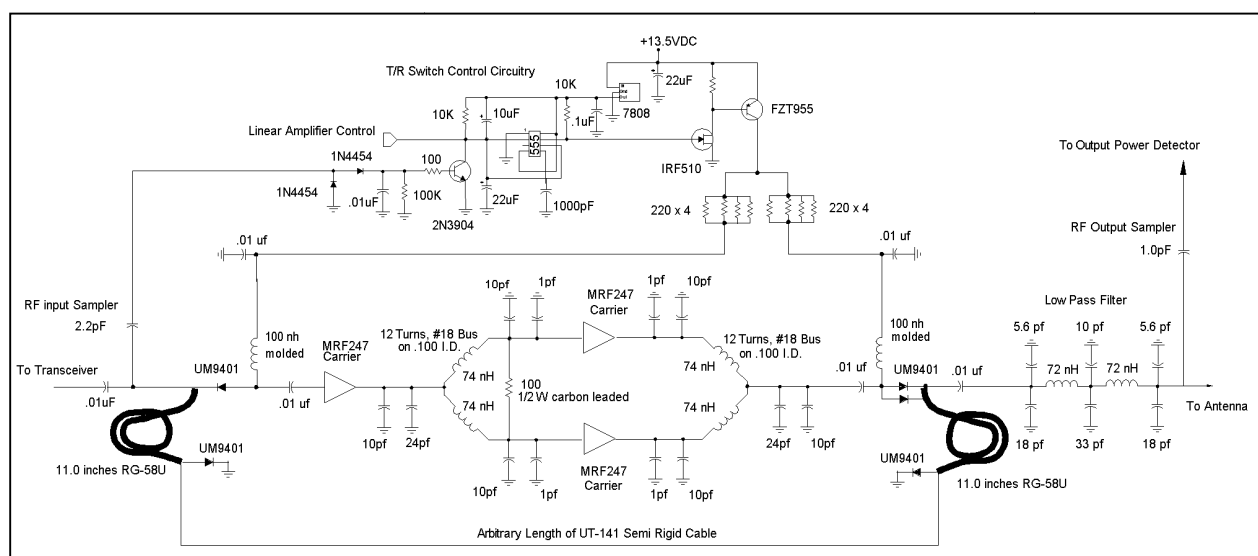


Figure 9. VHF Amplifier PIN Diode T/R Switch, Low Pass Filter and Control Circuitry

output T/R switch two diodes are used in parallel. This makes a parallel pair of resistors lowering the overall resistance of the switch when in the transmit state. Fig. 10 shows the parallel set of UM9401's in the output T/R switch. The MRF247 bipolars do generate some 2nd and 3rd harmonic components that must be filtered. To make sure that these products are well within FCC limits, a low pass filter is included in the output of the amplifier. The low pass filter provides an additional 30dB suppression of 2nd harmonics and -55dB suppression of 3rd harmonics.

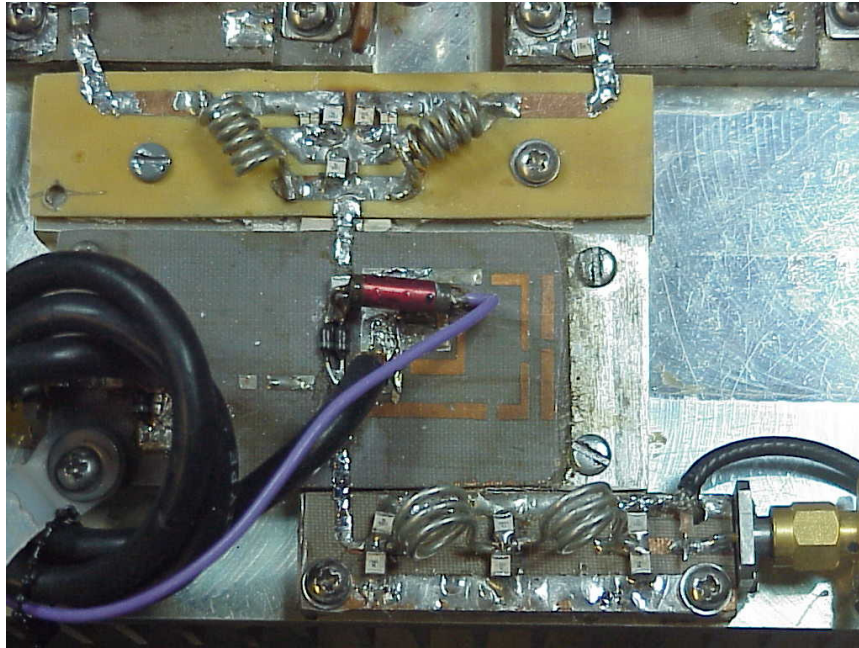


Figure 10. Output from Combiner cascaded with PIN Diode Output T/R Switch and Low Pass Filter

To achieve the lowest possible insertion loss a pair of coaxial relays were used in the UHF amplifier transfer switch. The relays are manufactured by Transco. As the schematic of Fig. 12 shows the relays are arranged so that the normally closed (de-energized) position is in the receive path. The same control circuitry is used with the IRF510 MOSFET providing a current sink to engage the +28VDC relays. A physically smaller switch can be used for the input switch as it is operated at the transceiver output power levels ranging from 5W to 20W. Therefore a smaller SMA connector style switch was used on the input. A N connector style switch was used on the output for 100W power handling. The coaxial relays are shown in Fig. 11.

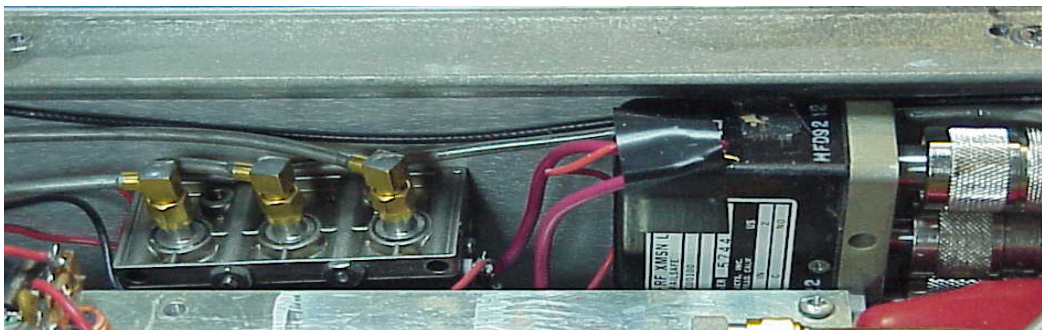


Figure 11. UHF Input and Output T/R Coaxial Relays Mounted on Side of Chassis

The second and third harmonic energy from the MRF648's is much lower and therefore additional filtering was not required for the UHF amplifier. The T/R switching circuit was built on a separate FR4 printed circuit board and can be remotely located anywhere within the chassis. The T/R switch control circuit assembly shown in Fig. 13 was mounted on the side wall of the chassis.

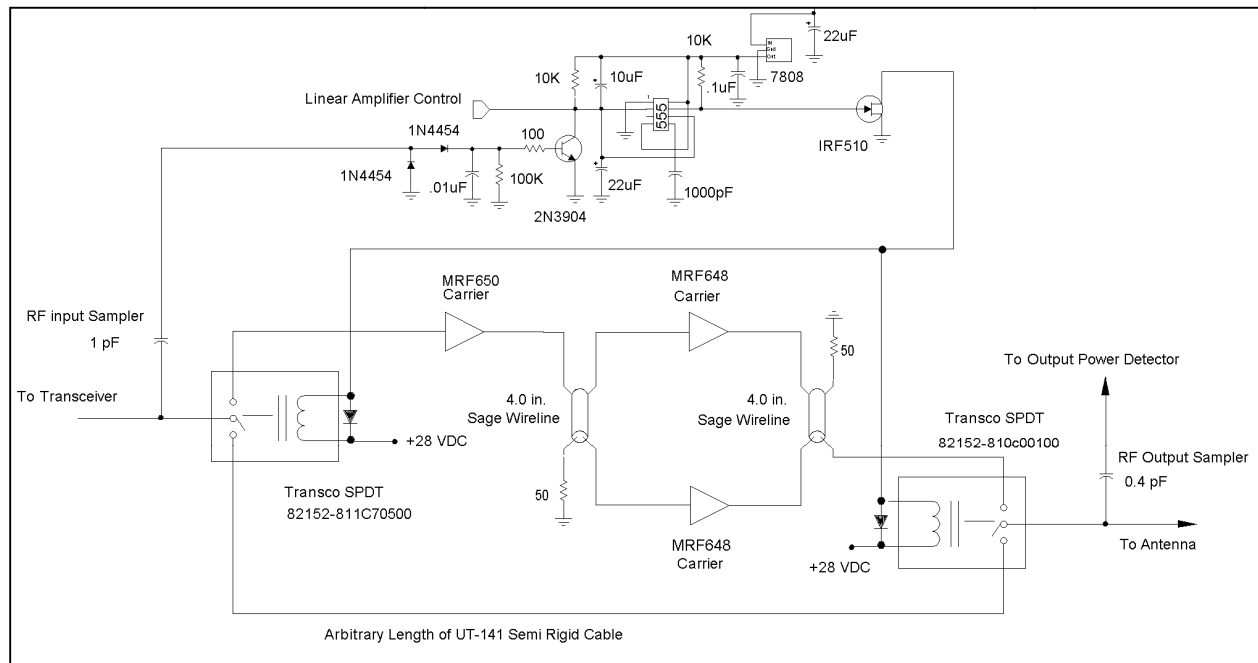


Figure 12. UHF Amplifier SPDT Relay T/R Switch and Control Circuitry

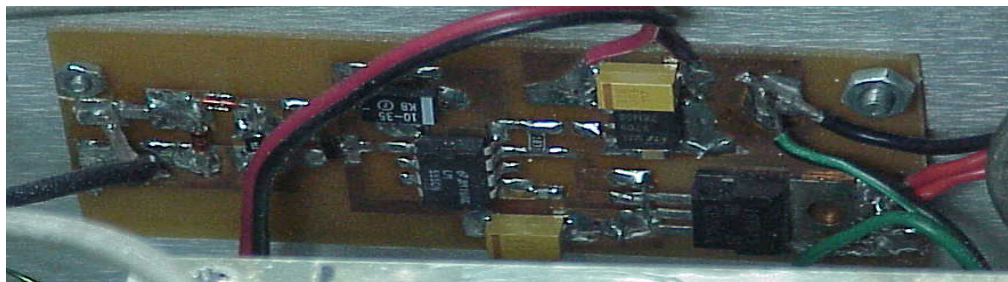


Figure 13. T/R Switch Control Printed Circuit Board Assembly

Power Supply Section

The power supply section consists of a separate high current +12VDC supply for the amplifiers and a lower power +28VDC supply for the UHF T/R relays and cooling fans. Both power supplies are Switched Mode Power Supplies, SMPS, manufactured by Vicor. The small size of the SMPS allows these units to be mounted in the same chassis as the rest of the amplifier. The +12VDC power supply voltage is trimmed up to 13.8VDC to maximize the output power from the RF devices. When either of the amplifiers is driven to full output power, the collector current can increase from its quiescent level of 6 Amps to a maximum of 22 Amps. Therefore

the +12VDC power supply must be capable of delivering [13.8v x 22A] 303W. For continuous usage and good long term reliability some de-rating of the power supply should be allowed. Thus a 600W power supply is a good choice for power capacity. A 75W unit is adequate for the +28V operation of the coaxial T/R switches. Because a separate 28V supply was included in the design the +12 volt cooling fans were wired in series and operated from this power supply. This reduces the B+ filtering requirements by keeping any noise generated by the cooling fans from the +13.8V supply of the amplifier. It is a good idea to include an additional AC line filter on the input of the SMPS to keep any switching harmonics from getting back on the AC mains. Both a fuse and circuit breaker were included for AC mains protection. A switch style circuit breaker provides over current protection and doubles as an on/off switch on the front panel.

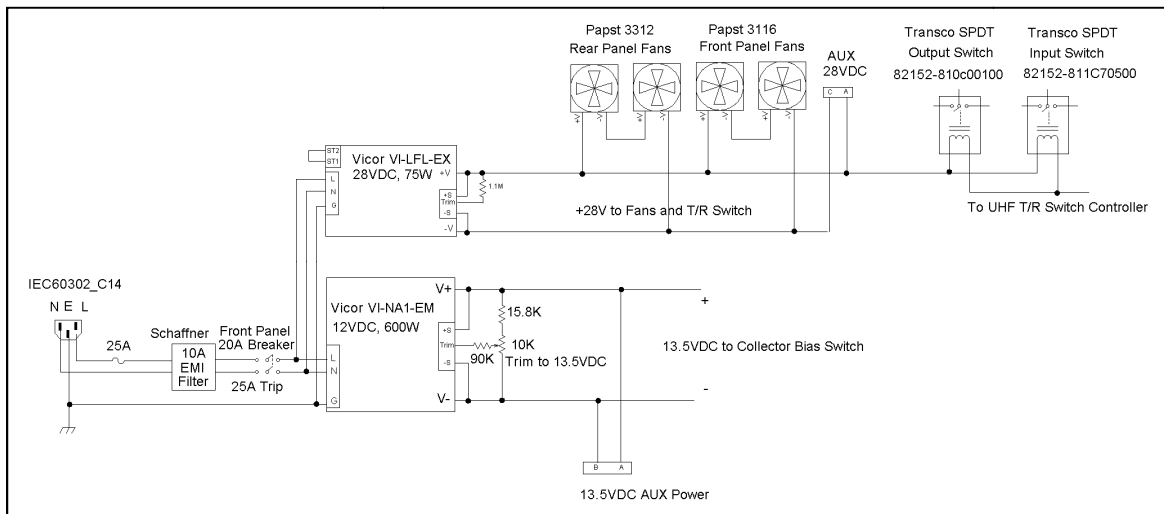


Figure 14. AC Mains, Power Supply and Cooling Fan Schematic

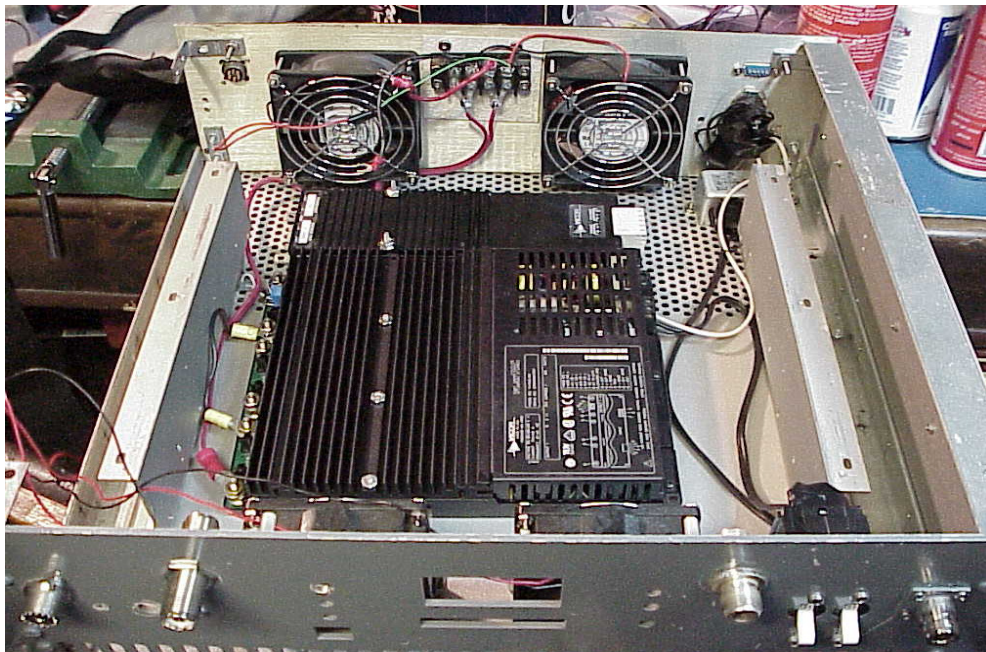


Figure 15. +13.8VDC and +28VDC Power Supplies Mounted in Bottom of Chassis

Collector Bias Switching Circuit

An electronic switch is used on the amplifier so that the RF device collector voltage can be remotely enabled and disabled. The switch is comprised of a pair of P channel MOSFETs that provide a 'high-side' switch for the +13.8V to the collectors. This circuit is particularly important for SSB satellite operation. Because the amplifier is biased for class AB operation, there is close to 100W of power dissipation even when there is no RF transmitted by the amplifier. The collector switch enables the voltage to the transistors only when there is RF going to the amplifier. Because the amplifier does not require any warm up time this is an efficient method of operating the amplifier. Another important consideration is that it is often helpful to disable an amplifier when operating full duplex satellite operation. Even when there is no RF signal present, the class AB amplifier will have gain which will amplify the thermal noise present at the input of the amplifier. It is possible for this thermal noise to bleed into the receive path thereby degrading the signal to noise ratio of the received signal. Disabling the power to the amplifier reduces this gain to zero thereby eliminating any potential problems with TX noise power density.

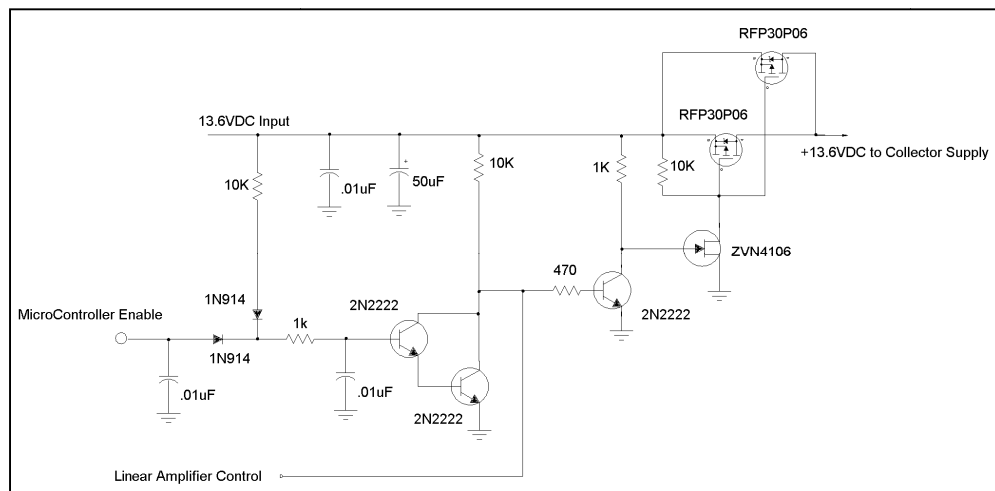


Figure 16. Collector Bias Switch Schematic

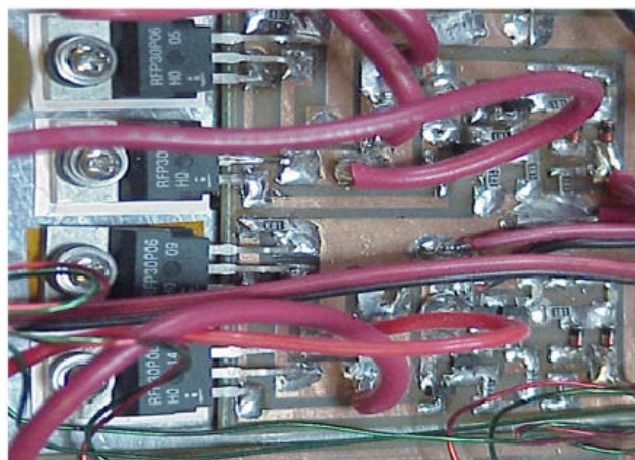


Figure 17. Collector Bias Switch Printed Circuit Board Assembly

Miscellaneous Monitor and Control Circuitry

Because the amplifier is intended to support remote operation there is extensive monitor and control circuitry included. These circuits provide inputs and outputs for interfacing the amplifier to a microcontroller and personal computer. These signals are present at Dsub connectors on the amplifier rear panel. The use of the computer interface eliminates the need to include metering on the front panel of the amplifier.

Current Monitor

From the single stage amplifier schematics of Fig. 1 and Fig. 3, note the use of a 0.01Ω resistor in series with the collector of each transistor. With quiescent bias levels of 2 Amps a 20mV voltage drop is measured across the resistor. At full power (7Amp bias) a 70mV drop exists. This provides a negligible voltage drop to the amplifier but the voltage can be used to remotely measure the current drawn by the amplifier stage. An LT1101 instrumentation grade differential amplifier is used to measure the voltage drop across the 0.01Ω resistor and amplify it with a voltage gain of 10. This voltage can be fed to an A/D converter to allow the microcontroller to monitor the current drawn by each transistor. Because of the limited number of A/D channels in the station's controller the voltage from all three sense resistors is summed to give a single output. This allows the controller and PC to monitor the total current consumed by the VHF and UHF three device amplifiers.

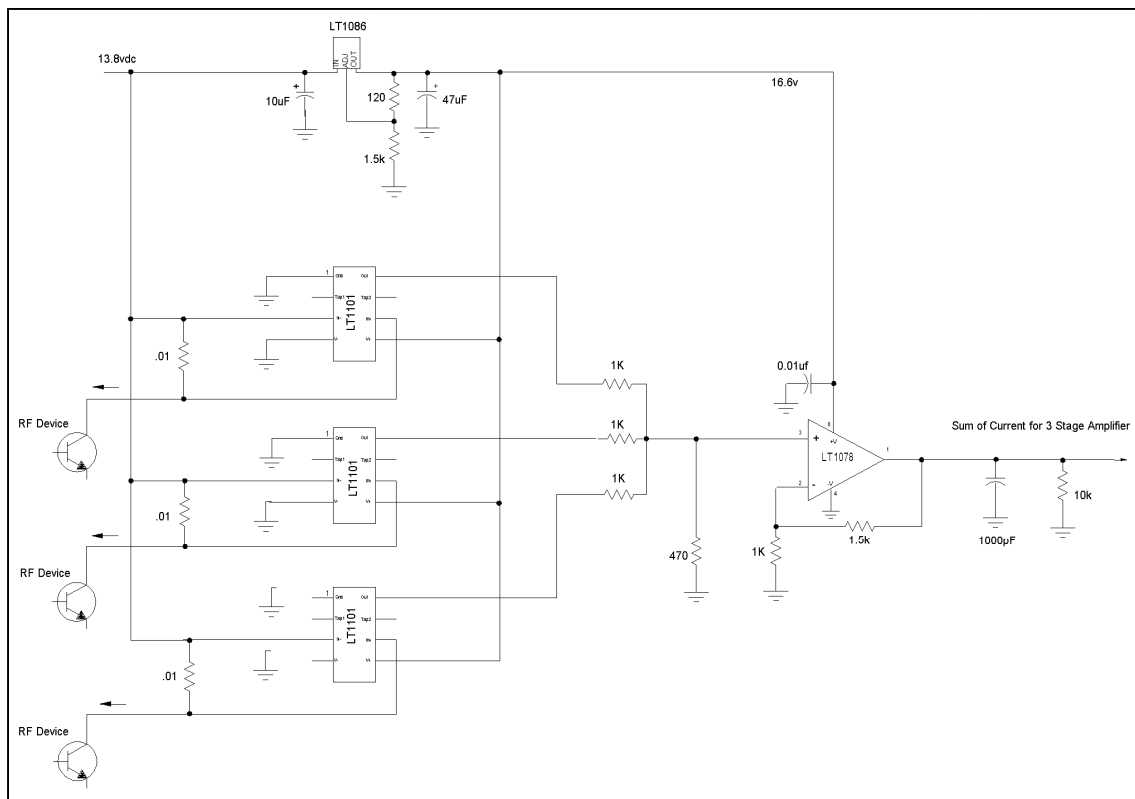


Figure 18. Amplifier Current Monitor Schematic

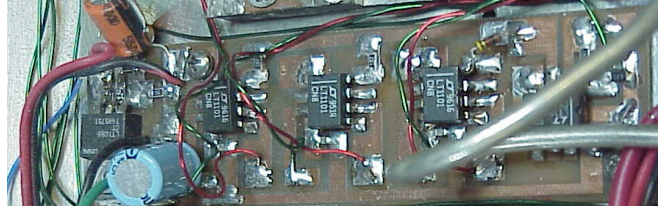


Figure 19. Amplifier Current Monitor Printed Circuit Board Assembly

Power Supply Voltage Monitor

The power supply voltage can similarly be input to an A/D converter as a power supply monitor. The A/D converter used in the station is limited to a +5VDC input so a voltage divider is attached to each power supply to reduce the voltage below +5VDC. The controller can then be calibrated for an accurate measurement of the power supply voltage. The amplifier interface schematic of Fig. 20 shows the implementation of the power supply voltage monitor.

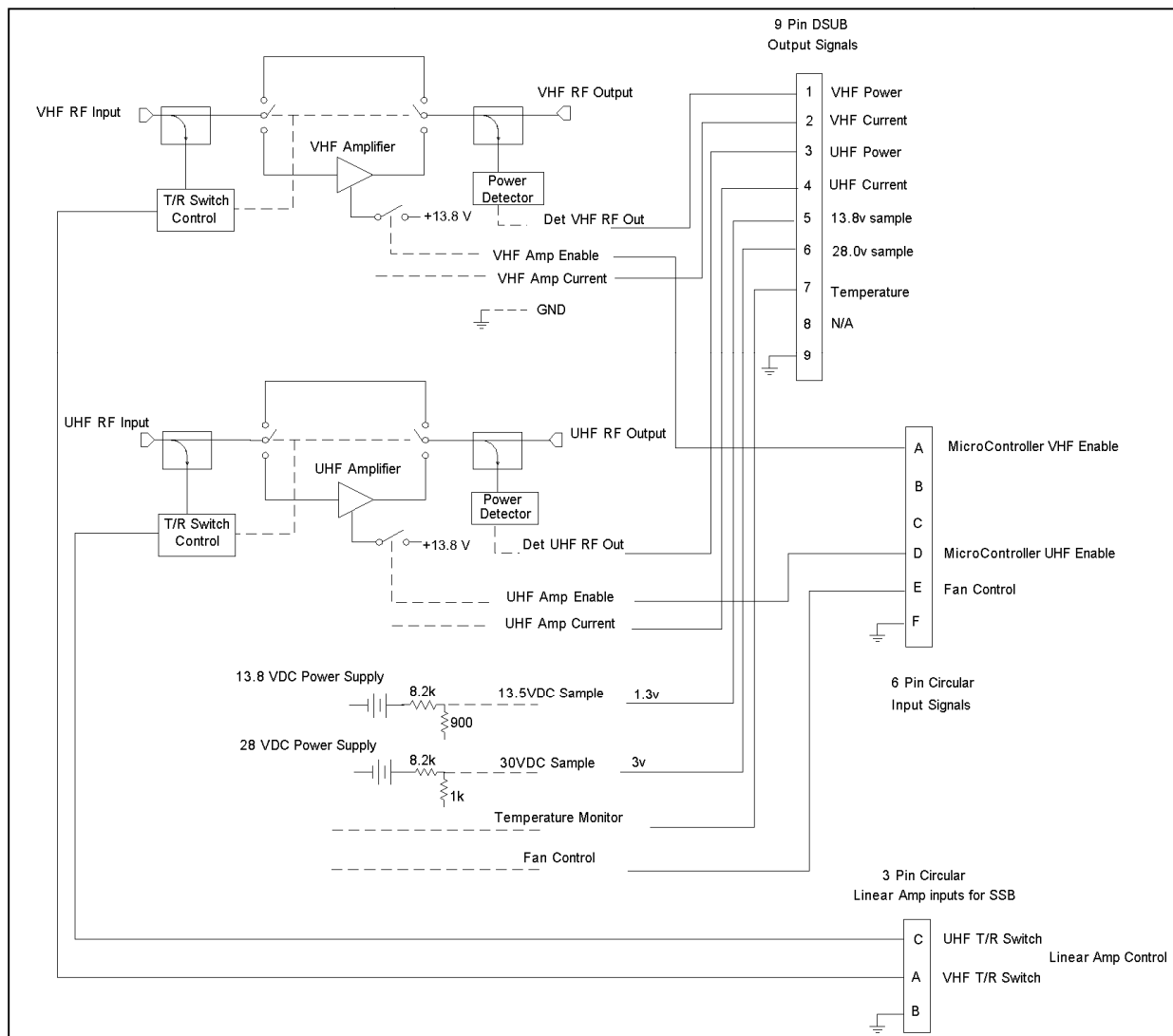


Figure 20. Overall Amplifier Schematic with Interface Signals

Amplifier Heat Sink Temperature Monitor

The heat sink temperature is monitored by an AD590 analog temperature sensor. The output of the sensor is buffered by an LT1101 as shown in Fig. 21. From Fig. 22 note that the temperature sensor makes good thermal contact via silicone grease with the heat sink by extending through a hole in the printed circuit board. A voltage is produced that is proportional to the heat sink temperature. This voltage is monitored by the microcontroller. This allows both manual and automatic on/off control of the chassis cooling fans. If the microcontroller senses a temperature above the programmed threshold the cooling fans can be automatically enabled.

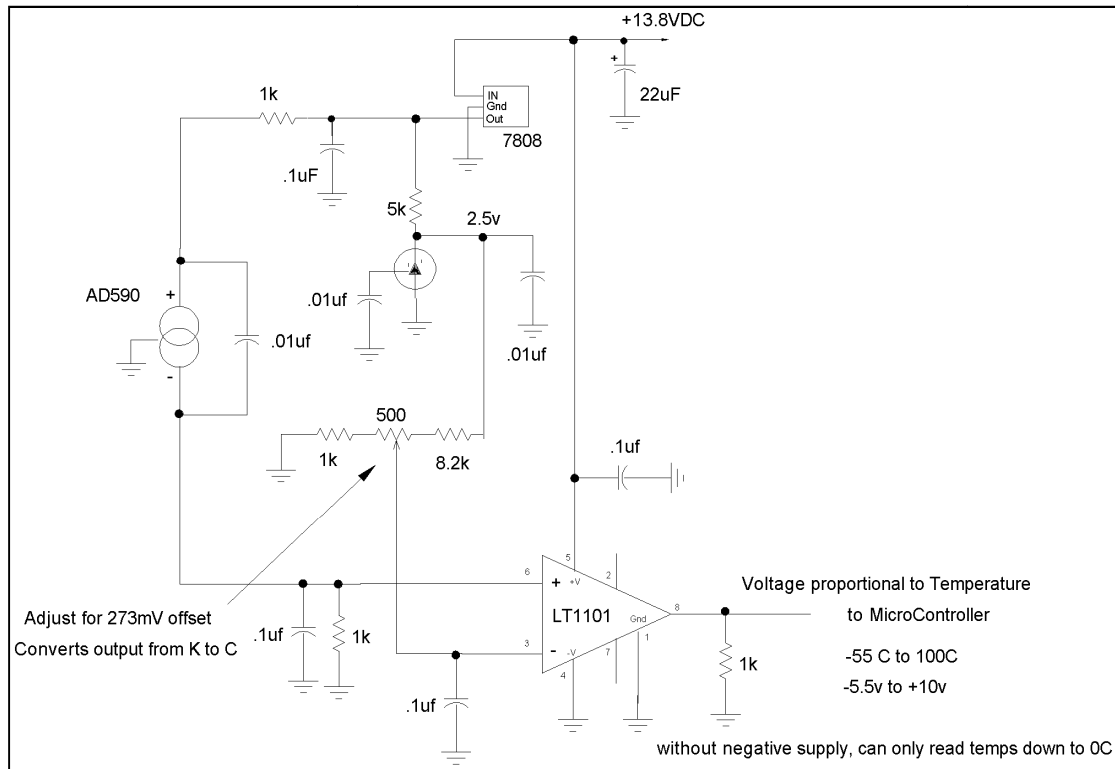


Figure 21. Heat Sink Plate Temperature Monitor Schematic

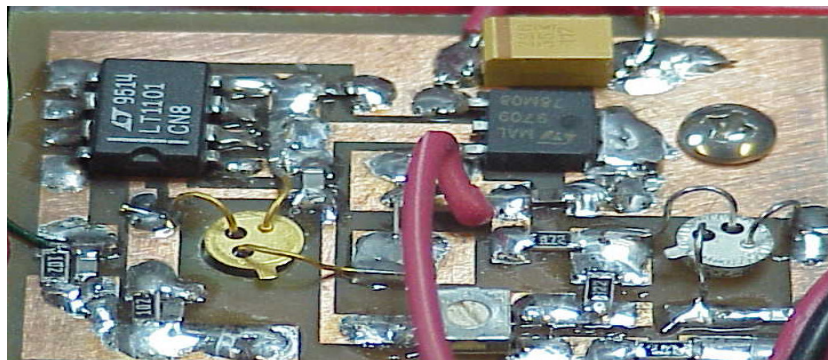


Figure 22. Heat Sink Plate Temperature Monitor Printed Circuit Board Assembly

Cooling Fan Switch

The cooling fans are enabled by the microcontroller using the control circuit of Fig. 23. A current sink provided by the IRF511 MOSFET provides a return path for the fan current. A Darlington pair of 2N2222 buffers the embedded controller output signal.

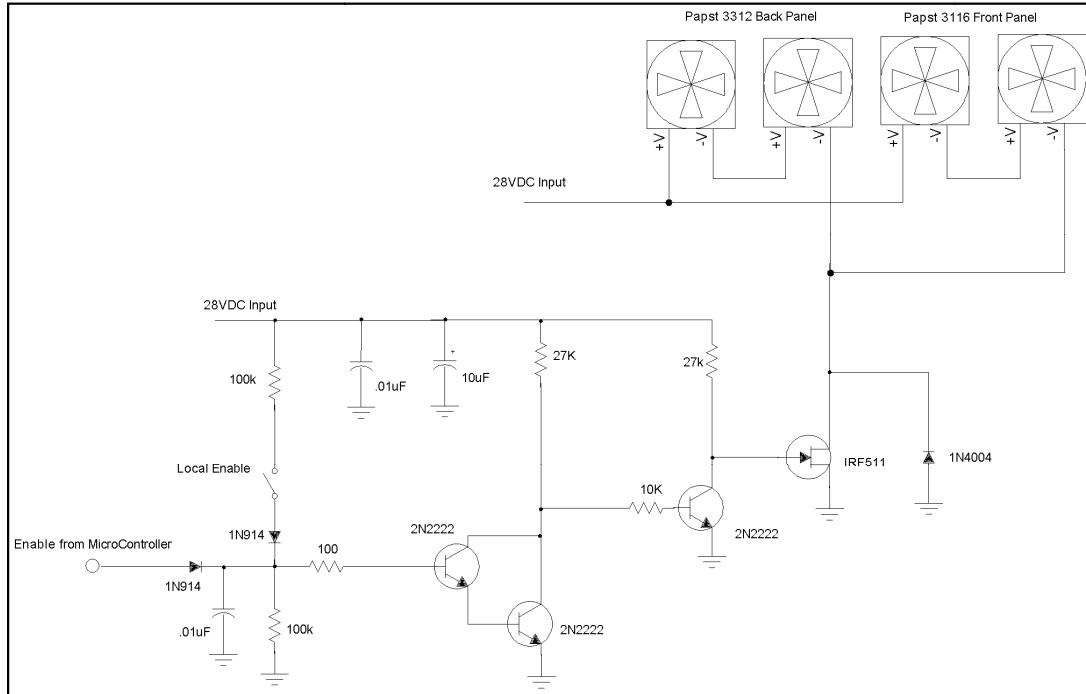


Figure 23. Front and Rear Panel Fan Enable Switch Schematic

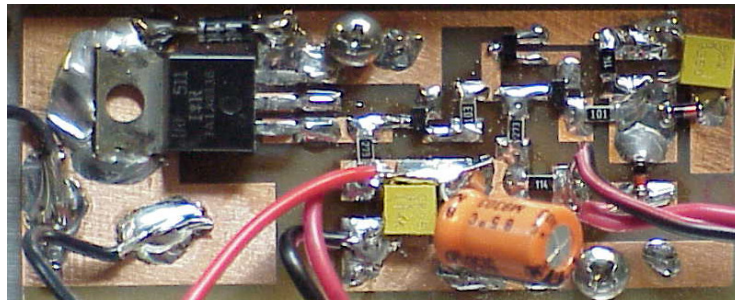


Figure 24. Fan Enable Switch Printed Circuit Board Assembly

RF Output Power Monitor

From Figs. 9 and 12 we have seen that the input and output power sampling is provided by a simple capacitor tap. A small capacitance value is selected so that it provides a very high reactance to the RF transmission line thereby reducing the loading effect. This type of sample does not provide any isolation or directivity to the sampled RF but is a simple and effective means of creating a much reduced sample of the RF power on the transmission line. The AD8361 RMS power detector is used to measure the RF output power. This gives a very accurate measurement of the output power independent of the modulation on the RF signal. The output of the detector is buffered by a LT1078 Op Amp and sent to the microcontroller.

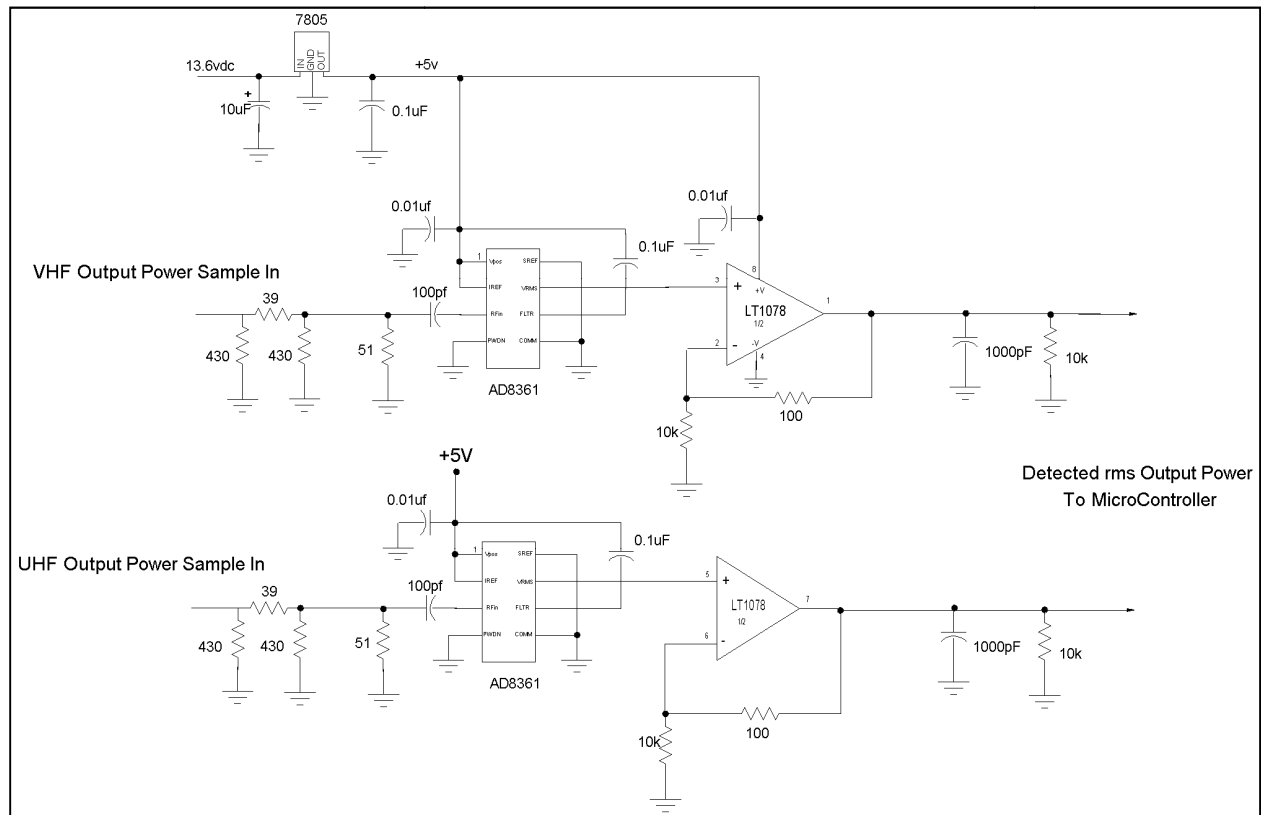


Figure 25. VHF & UHF Amplifier Output Power Detector Schematic

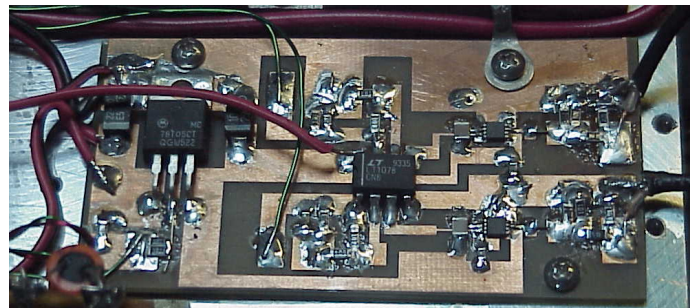


Figure 26. VHF & UHF Amplifier Output Power Detector Printed Circuit Board Assembly

Completed Amplifier Assembly

All components of the VHF and UHF amplifier are mounted to the common heat sink in 'brass-board' fashion. This is a very simple assembly technique that makes it easy to build and test the amplifier one step at a time. The heat sink plate is mounted on top of the power supplies with the fins facing the power supplies. The space above the power supplies including the heat sink fins provides a natural plenum for the cooling air to flow from the rear panel air intake to the exhaust on the front panel. The input and output connections to the amplifier are cabled to bulkhead connectors on the front panel. The entire dual band amplifier and power supplies are fitted into an old 19 inch rack mount chassis that is 24 inches in depth. The completed amplifier assembly is shown in Fig. 27. Facing the chassis the VHF amplifier is on the left hand side while the UHF amplifier is on the right hand side of the heat sink plate. All RF input and output connections are on the front panel.

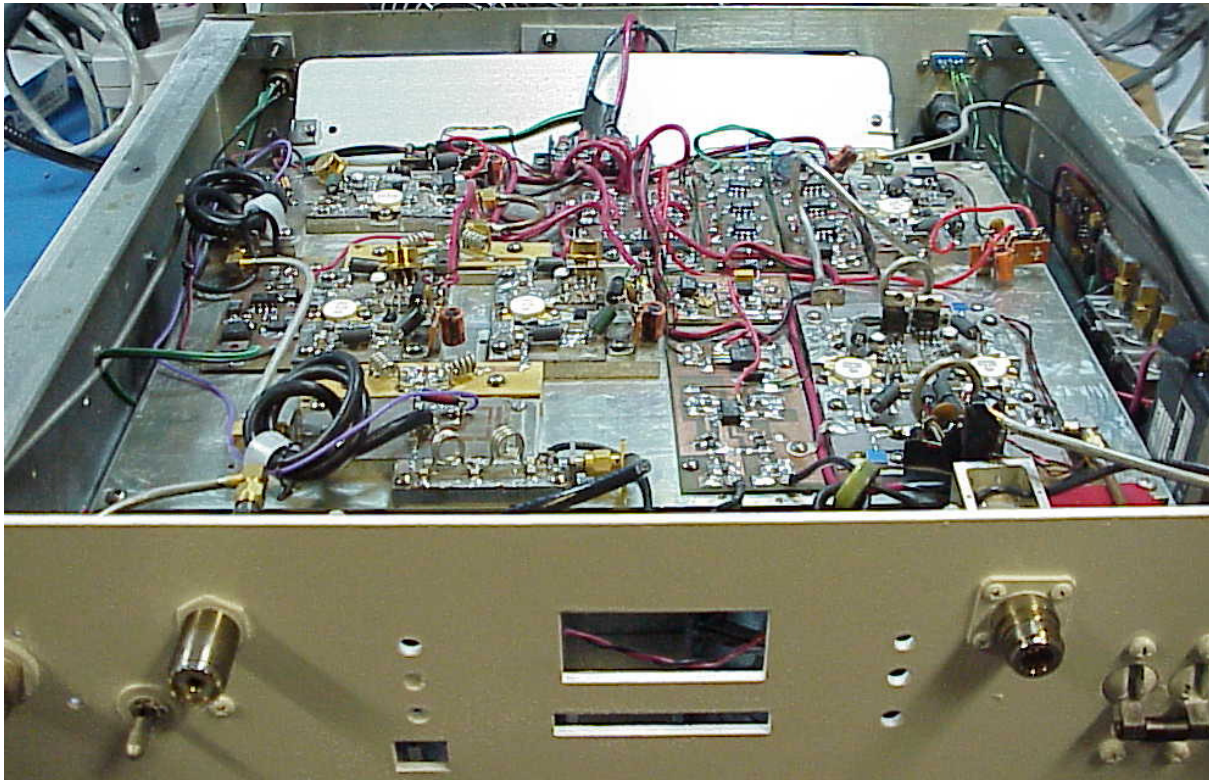


Figure 27. Amplifiers Mounted on Common Heat Sink on top of Power Supplies

Summary

The design and construction of a 100W VHF and 100W UHF amplifier has been presented. In addition to being extremely robust and versatile the amplifier is within the capability of many amateur radio operators. All components used in the amplifier were readily available by sources on the internet including many from Ebay. The VHF amplifier produces 125W of output power

across the entire 2m band. The UHF amplifier produces 105W across the entire 70cm band. The use of a microcontroller and PC opens up endless possibilities for user interfacing. The author uses a computer interface that is designed with Microsoft's Visual Basic Express 2008. This software is available for free download from Microsoft. The user interface for the amplifier is shown in Fig. 28.

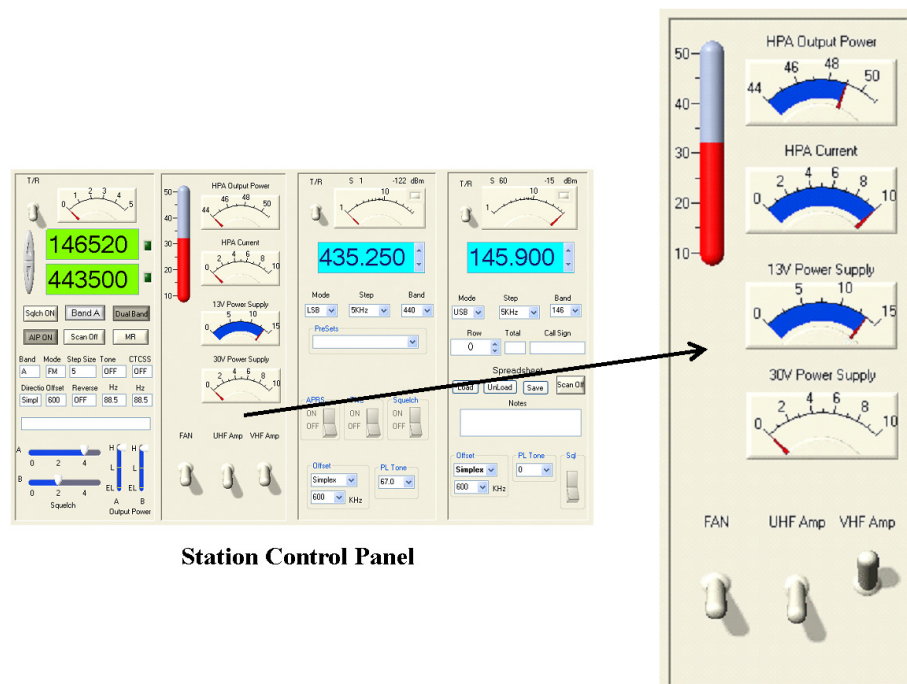


Figure 28. Windows PC Control Panel with Amplifier Interface

Fig. 29 shows the amplifier in service at the author's radio shack. The amplifier is used with a Yaesu FT-736R for SSB satellite work with 10W-20W drive power. It is also used with a Kenwood TH-D7 5W hand held for FM work.

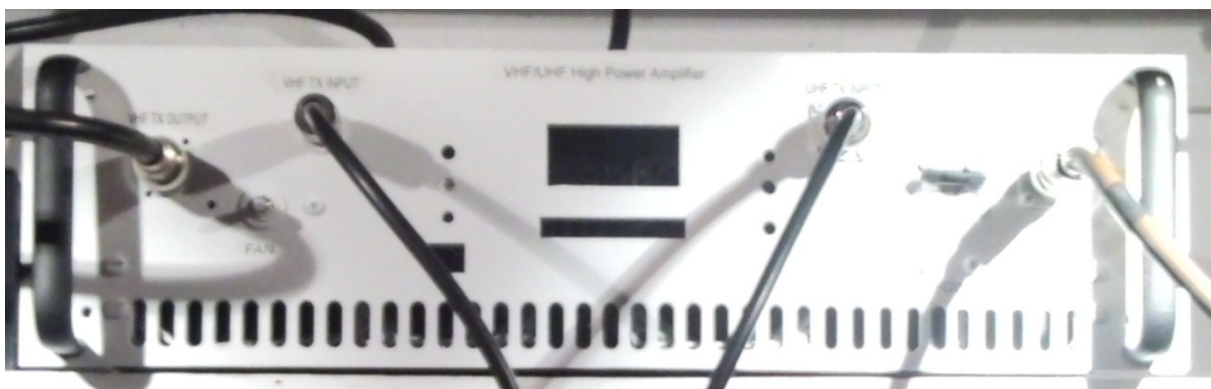


Figure 29. 100W VHF / UHF Amplifier in Service

Outreach:
Getting the
AMSAT
Word Out

Getting the AMSAT Word Out

An overview of AMSAT's publication, satellite news, satellite operations resources

JoAnne Maenpaa, K9JKM

k9jkm@amsat.org

Introduction

AMSAT has several resources, on line and in print, which highlights and supports Amateur Radio in space. While these are well known to experienced satellite operators, the main purpose of this paper is to summarize what is available to help newcomers to our exciting aspect of amateur radio find and explore the theory as well as the practical how-to's of satellites. It gives the experienced amateur radio satellite operator a list of resources which may be useful to "elmer" the new guys and help get more Amateur Radio operators started on a self-learning adventure.

AMSAT's satellite operations resources include:

- The worldwide web – <http://www.amsat.org>
- The AMSAT Journal
- AMSAT News Service
- E-mail reflectors
- Books
- AMSAT Presence on the Social Networks

These resources are provided by a team of volunteers who are working daily to keep up with the latest Amateur Radio satellite news:

- Gould Smith, WA4SXM – AMSAT Vice President of User Services
- Lee McLamb, KU4OS – AMSAT News Service Editor
- Dee Interdonato, NB2F – AMSAT News Service Editor
- Bill Hook, W3QBC – *AMSAT Journal* Assistant Editor
- Ed Long, WA4SWJ – *AMSAT Journal* Editor-in-Chief
- James French, W8ISS – AMSAT Weekly Satellite Report Editor
- Rick Hambly, W2GPS – Interim Webmaster (maintenance & emergency repairs)
- Paul Williamson, KB5MU – E-mail List Administrator
- JoAnne Maenpaa, K9JKM – AMSAT News Service Editor, Assistant Editor *AMSAT Journal*
- Bernhard Jatzeck, VA6BMJ – English-German Translations for AMSAT Journal

AMSAT's Web Pages

The second generation, which is the current version of the AMSAT web pages, (<http://www.amsat.org>) was designed by now-retired webmaster, Emily Clarke, N1DID. She undertook the effort to modernize the first generation of AMSAT web pages using newly available graphics and web tools which were not available during the early days on the web.

These first generation web pages were created and maintained by Paul Williamson, KB5MU. Rick Hambly, W2GPS has stepped up to be AMSAT's interim webmaster as the Board of Directors studies future options for our presence on the web. Rick ably steps in for emergency repairs and maintenance on the new web site to keep us on-line.

You may note the use of the words "interim" and "maintenance". In summary, AMSAT needs many able-bodied webmasters to volunteer to create our new presence on the web. If the volunteer help was available several projects have been proposed as part of this web upgrade:

- Creation of members-only login with access to special features. This will also require the modernization and on-going maintenance of AMSAT's membership database along with the query software to support login requests. Members only access on the web has been proposed to allow:
 - Access to a searchable, topical threaded web forum on satellite topics which may someday provide an upgrade path from existing text-only e-mail lists.
 - Access to AMSAT Journal e-Zine in PDF format.
 - User management of your desired on-line features.
- The web team is aware of broken links as side effects from emergency maintenance.
- Migration to a content management system such as Joomla or equivalent systems as part of the third generation of our web pages.

The web upgrade is at this point based on requests and proposals from AMSAT's user community. Until a team of volunteers is available progress will be remain slow. These plans represent a compilation of several requests and discussions as to AMSAT's future direction on the web. At this time these proposals have not become organization policy and are presented here to spur further imagination, discussion, and planning. If you are web-savvy and have the time to help this is your opportunity to make a key contribution to AMSAT and the Amateur Satellite world.



The AMSAT Journal

AMSAT's publication efforts include the production of our bi-monthly "*AMSAT Journal*" which keeps members abreast of the latest efforts of the organization in the fields of spacecraft and ground station applications. This magazine is one of the principal membership benefits of joining AMSAT.



AMSAT Journal's Editor-in-Chief is Ed Long, WA4SWJ. Ed welcomes article submissions for the Journal from all Amateur Radio operators. When writing articles for Amateur Radio publications the *AMSAT Journal* appreciates you use of this publishing forum if possible.

Excellent examples of articles being sought for The Journal are the Symposium Papers in this proceedings book. No special formatting or writing background is required. All you need to do is tell your fellow satellite operators the who, what, where, and why of your satellite project. Refer to the appendix at the end of this article for a copy of the *Journal Writer's Guide*.

The AMSAT News Service

This weekly e-mail service keeps members up to date on the latest developments within the hobby. Additionally, it delivers the up to the minute information needed by ham radio operators around the world on the status of each spacecraft presently in orbit, including their operating condition and associated operating frequencies.

To receive the AMSAT News Service Weekly Bulletins delivered to your e-mail box subscribe to the ANS List as described in the section on the AMSAT E-Mail Lists & Reflectors. A subscription to the ANS List will bring you weekly copies of:

- AMSAT News Service Weekly Bulletins and Special Satellite Bulletins when the news occurs.
- AMSAT Weekly Satellite Report

The ANS bulletins were originally designed for worldwide transmission via the packed PBBS network. ANS editors have discovered that while the PBBS systems have pretty much disappeared in the United States that this format is still widely used in many other places around the world. A search engine lookup of the ANS bulletins reveals that AMSAT's News Bulletins continue to be widely distributed in at least 30 to 40 different country's packet relay systems. This is the principal reason the existing format or the ANS Bulletins has been maintained.

People sometimes ask about the "strange numbers" at the beginning of the news bulletins. The numbering system was designed for PBBS relay systems. As such each PBBS bulletin required a unique message ID to reduce duplicate messages. For example, SB SAT @ AMSAT \$ANS-248.01 categorized the packet message into the satellite category of the menu. To further generate the required unique message ID the '248' represents the day number of the calendar year; the '.01' further differentiates messages transmitted on the same day.

All Amateur Satellite operators are invited to send your news to the AMSAT News Service via e-mail to ans-editor@amsat.org. The deadline for each weekly ANS bulletin is every Thursday evening.

AMSAT E-Mail Lists & Reflectors

AMSAT-BB

The **AMSAT Bulletin Board** (AMSAT-BB) public mailing list carries general AMSAT information and discussion. The purpose of this mailing list is to provide a forum for general discussion of any satellite-related topic.

SAREX

The **Space Amateur Radio Experiment** (SAREX) public mailing list contains information and discussion pertaining to amateur radio operation on manned space missions, including the Space Shuttle, Mir (formerly), and the International Space Station. The name is leftover from the Shuttle Amateur Radio Experiment (SAREX) aboard Space Shuttle flights. It is now mainly concerned with ARISS operations aboard the International Space Station.

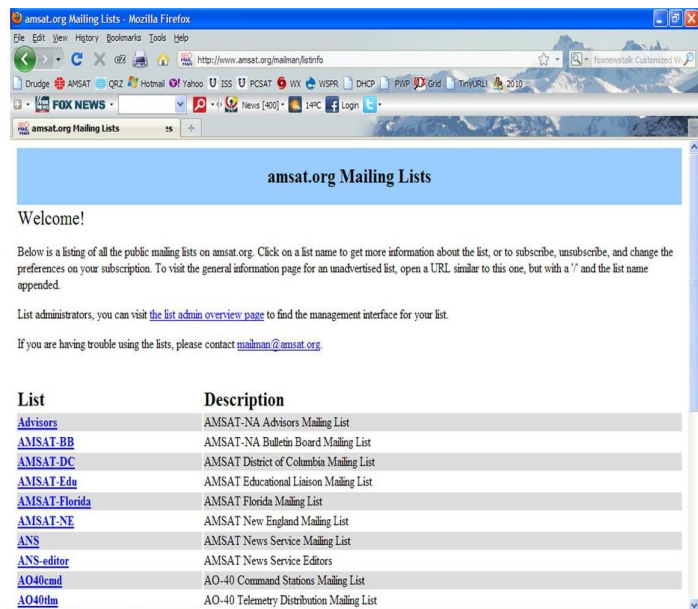
And, Other Lists ...

There are also regional AMSAT public mailing lists (e.g., AMSAT-DC, AMSAT-Florida, and AMSAT-NE) and numerous private mailing lists (e.g., Board of Directors, Officers, AO-51 operations, etc.). A summary of all of AMSAT's e-mail lists can be found at: <http://www.amsat.org/mailman/listinfo>.

A Gentle Reminder Regarding the AMSAT Acceptable Use Policy

Anyone can read the messages posted on any of the public mailing lists, and many people from around the world do so. Our audience includes AMSAT members, board members, and officers. At any given time, the readers may also include amateur radio operators, shortwave listeners, minors, potential financial donors, potential launch providers, officials from other amateur radio and satellite organizations, officials from international space agencies, and equipment suppliers and manufacturers. Since the archives of the public mailing lists are available on the AMSAT website, the contents of individual messages are easily found using common search engines. Because of this wide readership, AMSAT insists that messages posted on its public mailing lists conform to this Acceptable Use Policy (AUP). Acceptable content has been defined by AMSAT Board of Directors to include:

- We embrace diversity of opinions and values. In order to preserve a constructive environment, we do insist that messages contain appropriate content and are respectful of the members and readers.
- All posts should include the author's first name and call sign, or full name if not currently licensed.
- In general, messages for the AMSAT mailing lists should be related to amateur radio satellites.
 - Announcements of general interest, including but not limited to AMSAT news, meetings, satellite availability, and DXpeditions.
 - Technical discussions, including the physics of space flight, modulation techniques, satellite design, RF path loss calculations, noise figure, inquiries and suggestions about choosing equipment, learning operating techniques, and troubleshooting problems.
 - Discussion of AMSAT plans and policies in ways that foster better understanding of the opportunities, trade-offs, and limitations that AMSAT faces, and constructive suggestions for improvement.
 - Posting of amateur radio satellite-related equipment and software available for sale.



Strong disagreements on issues are inevitable, but the AMSAT mailing lists are not the place for exchanges which become spiteful, unproductive exchanges. If you must have a heated exchange, it should be conducted privately and not in public on a mailing list. We define unacceptable content as anything that is:

- Illegal
- Insulting, abusive, harassing, or threatening
- Knowingly false or misrepresentative

Satellite Operating Books

AMSAT also publishes an extensive array of books centering on specific aspects of our mission. Software and other resources are also made available on CD.

- 2009 ARRL Satellite Handbook
- AO-51 Publication
- 2009 40th Anniversary AMSAT Symposium Proceedings
- 2009 Getting Started with Amateur Satellites
- 2010 Getting Started with Amateur Satellites
- AMSAT The First Forty Years

Publications available from the AMSAT Store include:

- AMSAT Journal on CD-ROM 2001-2005
- 2008 AMSAT Symposium DVD

Software resources available from the AMSAT Store include:

- MacDoppler Tracking Software
- SatPC32 on CDROM
- SatPC32 License key for downloaded version
- Digital Disk with WISP32 Software

These resources can be ordered from the on-line AMSAT Store:

<http://www.amsat-na.com/store/categories.php>



AMSAT Presence on the Social Networks

Twitter

AMSAT's presence on Twitter is maintained by Drew Glasbrenner, KO4MA. When an interesting amateur satellite event or opportunity presents itself Drew says he can send out any announcements or blurbs via AMSAT's twitter account. Just send them to ko4ma@amsat.org in 140 characters or less. We have almost 600 followers, and often are retweeted. When the timeframe is too short to consider using an ANS bulletin to publicize your event Twitter can be used to get the news out quickly. Check out @AMSAT on <http://twitter.com/> .

Facebook

While not AMSAT per se, the Amateur Radio on the International Space Station (ARISS) organization now has a Facebook page which was established by David Jordan, AA4KN. See the new ARISS Facebook page at <http://www.facebook.com/pages/Amateur-Radio-on-the-International-Space-Station/143541532324016>.

Additional Opportunities

As mentioned previously, please keep AMSAT in mind when releasing your Amateur Satellite news. The AMSAT News Service and The AMSAT Journal are always ready to publish your items! Often AMSAT's editors see satellite news released to the ARRL instead of our forums.

When you write an article for other Amateur Radio magazines consider including a sidebar describing AMSAT and include a pointer to on-line resources. You'll be giving an interested reader access to additional resources and perhaps AMSAT will gain a new member.

An example of an excellent how-to work FM satellites guide written by Clint Bradford, K6LCS is included in the Symposium Proceedings. Clint invites you to use his guide as-is or as a starting point for your own style of writing and presentations.

If you are thinking of setting up satellite operating demonstrations at club meetings or hamfests take a look at Keith Pugh's, W5IU paper in these proceedings regarding "Successful Hamfest Satellite Demos".

The AMSAT User Services Crew

Here are photos and a short biography of some of the AMSAT User Services crew who had the chance to beat the deadline and send me some stuff ...

Gould Smith, WA4SXM – AMSAT Vice President User Services



Gould was licensed in 1976 and holds an Advanced Class ticket. He's been an avid amateur satellite user/operator since 1988. Gould is one of the AO-51 Command Stations as well as serving as an AMSAT Board of Directors member. Gould is the Project Manager of the ARRISat-1 project team.

On terrestrial projects Gould is the team leader LVB Tracker Box project for AMSAT. He wrote documentation and a web page for building, configuring and installing the interface box with satellite tracking software. He is a published author having researched and written a chapter on small satellites for the AIAA book, "Small Satellites, Past, Present and Future", published in 2008. He also researched and wrote a book on the AO-51 satellite, published by

AMSAT in 2005.

Dominick "Dee" Interdonato, NB2F – AMSAT News Service Editor

Dee was first licensed in 1964 and presently holds an amateur extra license. His career includes avionics in the US Army and a stint in Vietnam. He has also worked in 2-way radio, marine electronics, satellite navigation and communications equipment. He is a supervisor at present for the Communications Shop of the Port Authority of NY & NJ.



Dee has served chairman of the local amateur radio club and wrote its bulletin for 10 years. He is also a VEC and has given many presentations on Satellite use, Demo's and How to's for several clubs and organizations in the New Jersey area. Manning the AMSAT table at a hamfest is one of his pleasures. Dee has been a key support staff person for many years at the AMSAT booth at the Dayton Hamvention.

Lee McLamb, KU4OS – AMSAT News Service Editor



Lee holds an extra class license. He has been active on Amateur Satellites for years having first started with AO-10 as ZD8LM from Ascension Island. Lee is a past Executive Vice President of AMSAT. He has also mentored the Small Satellite and Cubesat development teams and provided AMSAT's interface to these university space programs. Lee's day job involves launching the Atlas and Falcon rockets from Cape Canaveral Air Force Station in Florida.

Ed Long, WA4SWJ – Editor-in-Chief of the *AMSAT Journal*

Ed started ham radio in 1970 as WN8IKV and then WB8IKV when he upgraded to General and then Advanced. Then the FCC gave him WA4SWJ when he moved to Virginia and he's held this call-sign ever since. Ed currently lives in the very nice small town of Belleview, FL near Ocala.

Ed wrote, "I'm not super active but I like SSB, CW, PSK31 (all QRP) and occasional FM repeater work. Believe it or not, I have never made a satellite contact with my own equipment. I have plenty of equipment to get on even including S-band. I just never seem to have free time to do it. When I'm not working, traveling on business or working on projects at home, I'm working on the *Journal*! One day soon I'll get on the sats and make some contacts. Watch out for the rare editor grid! (not the grid - the editor)"



Ed also loves to build vacuum tube audio amplifiers and has built over 20 different amplifiers. His home theater is powered by 5 tube amplifiers that he built. He also builds speakers and has built 5 different high fidelity speaker sets. Ed has gone to the Dayton Hamvention every year except one since 1974.

Professionally Ed is the Director, New Product Development - Americas Region for SPX Flow Technology where he is responsible for all new product development in North and South America. He is based at the Ocala, FL plant.

JoAnne Maenpaa, K9JKM – AMSAT News Service Editor, Asst. Editor *Journal*

JoAnne was first licensed in 1973 and she holds an Extra class ticket. Her main Amateur Radio activities include working the low orbit satellites, ISS packet, learning software defined radio and building a micro-wave-capable station. She has enjoyed a 20+ year career in the telecommunications industry working as a communications systems engineer for FermiLab, Motorola and Northrop-Grumman. Her second career is as a registered nurse in a hospital cardiac unit. The ham shack in the photo is where the ANS bulletins originate.



James French W8ISS - Weekly Satellite Report Editor



James has been licensed since August 1991 when I got the call KD4DLA after taking the test in Seminole, Florida after two weeks of studying the tech guide the previous July. He has editing the Weekly Satellite Report for seven years.

James was originally introduced to satellites by Ozzie, N4SCY at an AMSAT Symposiums in Orlando, Fl. Ozzie showed my grandfather (W1DLP) and him the Phase 3D lab out at Orlando International Airport and James says he was was hooked, line, and sinker from then on. He traveled from the St. Petersburg area to Orlando roughly once a week to help out where he could at the lab

until July 1996 when he moved up to the Detroit, MI area and has been there since enjoying the change of seasons again.

James' other interests include packet radio, in operating on any of the VHF and above bands including the microwaves where he is currently heavily involved. His highest band so far has been 24 GHz. James been starting to enjoy contesting as of late with doing the VHF+ contests in the summer and operating from the Red Cross club station on HF in the Winter as W8PGW with the ARROW Communications Association in Ann Arbor, MI. where you will hear him calling CQ on either of my preferred HF bands, 160 or 10m.

James' day job is with a printing company as a press operator on a couple of 4 color offset heat-set web presses in Taylor, MI. where he's been for 11 years now.

Appendix: Author's Guide

The AMSAT Journal

By Ed Long, WA4SWJ

Editor, The AMSAT Journal

First, what type of papers is *The AMSAT Journal* interested in?

The AMSAT Journal is a moderately technical journal and is also an amateur satellite news/operating-oriented publication. We look for technical articles related to satellite operations such as new antenna systems, new methods of data communications, new software applications, new satellites, satellite tracking or other technical satellite projects. We also look for news about satellite-oriented operating events like Field Day, SKN, special event stations working the satellites, ARISS, satellite operating awards, international satellite operations and projects and satellite DX/Dxpediton operations. Anything of general interest to hams operating on the Amateur Radio satellites or ISS is of interest.

It's easier to write for *The AMSAT Journal* than you might think. While a well-written submission is easier for the editor to deal with, your work doesn't have to be perfect. Write your article as best you can and our editor will work with you to remove any flaws there might be. Pick a topic that you're passionate about and just start writing!

What we do not accept

There are a several things that will result in immediate return of your article for additional work. A list follows:

- ♦ Profanity. Please avoid even mildly profane words such as "hell."
- ♦ Sexual content or discussions of any kind. This includes links to Web sites with sexual content or discussions.
- ♦ Depictions of violence of any kind. This includes links to Web sites that depict violence of any kind.
- ♦ Personal attacks on anyone.
- ♦ Comments demeaning to others based on gender, race, religion, age or nationality or links to Web sites with such content.
- ♦ Articles that are not original work and/or articles that are owned by other copyright holders.
- ♦ Political discussions (other than the politics of Amateur Radio or those pertaining to Amateur Radio).

Preparing your manuscript

Once you have written your article you can e-mail your manuscript to journal@amsat.org as a word processing file attachment. Although our editors work primarily in Microsoft Word and PageMaker, we are capable of reading other word-processing formats as well.

When preparing your electronic manuscript for e-mailing, please observe the following guidelines:

- ♦ Please do not attempt to format the document to look like *The AMSAT Journal* pages. Our page formatting software will do that automatically. Just write the text entirely across the page similar to how this document is written. That is fine and is much easier for the editor to use. Also, please don't use multiple columns on the pages. The editor just has to remove them prior to placement. If you need multiple columns for tables and so on, please advise us and we can put them into table programs available in our page layout software. In your manuscript use tabs, not spaces, to separate columns of data. Tabs provide proper alignment whereas spaces do not due to a variety of electronic typesetting reasons. Alternately, use the table function in your word processing software to create the table. Ideally those should be at the end of the article or in a separate file.
- ♦ Please do not embed images, graphics or illustrations within the text file itself. Please send text and graphics as separate files. The reason for this is that the editors must move graphics around to fit the Journal pages appropriately. Removing embedded graphics from the text and saving them separately is usually quite difficult and the resolution sometimes degrades. Also, graphics and pictures may need to be processed to make them appear properly in the black and white/grayscale printing used by *The AMSAT Journal*. So, please send each graphic as a separate file. This allows the editor maximum flexibility for page layout.
- ♦ Please use standard nomenclature for parts, units, etc. as well as standard abbreviations. If you are in doubt about an abbreviation please go ahead and spell it out. It is easier to understand what you mean.
- ♦ When typing your manuscript please do not put two spaces after a sentence (after the period). This is a habit many of us got into when we were in typing school using old manual typewriters. With modern word processing and page layout software this only causes bad looking sentence spacing. The editors routinely remove extra spaces so please save them the time needed to do this by leaving the extra spaces out. Thanks!

- ♦ Please include captions for all tables, images, graphs and illustrations at the end of the file or in a separate manuscript file referring to each figure with an appropriate caption.
- ♦ Please make sure your name, call sign and e-mail address are included within the manuscript file, preferably at the beginning just under the title. We routinely publish your name and e-mail contact information so readers may contact you with questions.

E-mail your manuscript, charts and graphics/photos to: journal@amsat.org

While not preferred, you also may send your manuscript to us by postal mail. Don't let the fact that you don't use computers discourage you! We can scan a paper manuscript and convert it to electronic format. Print or type your manuscript in double-spaced format on one side of each 8 ½ X 11 inch sheet of paper. Leave at least a ½ inch margin around all sides of the text on each page. The top of each manuscript page should have a heading. Include the author's name, a key word or two from the title and a page number. It's a very good idea to make a copy of your article before sending it to *The AMSAT Journal*. Sometimes things get lost in the mail and your work could be lost – unlikely, but it happens. The Journal editorial address is printed in the masthead on page 3 of every issue. Your article may also be mailed to AMSAT headquarters in Maryland and it will be forwarded. The headquarters address is also in the masthead.

Additional information on manuscript generation

Use standard abbreviations for text if you feel they are needed. Use other abbreviations and acronyms only after they first have been spelled out. For example: central processing unit (CPU). Then CPU may be used in the remainder of the text.

In accordance with IEEE standards, electrical units are capitalized when abbreviated and appear in lower case when spelled out. For example: "0.2 F" or "0.2 farads". Either US Standard or metric length units are acceptable, as long as one or the other is used consistently.

Place any footnote references in the text as superscript numerals. Put the footnotes and bibliographical information at the end of the manuscript in numerical order. Double-check all of your references to be sure they are correct. Include complete reference information, such as the author's name, book or article title, publisher's

name and address, date of publication and page numbers so readers may refer to those if they wish.

Label all figures with a number (i.e., Figure 1 or Table 1, etc.) and place these at the end of the manuscript. Please do not insert them in the middle of the manuscript text, and do not put captions directly on the graphics themselves. Place captions below each picture. Provide a list of figures by number, along with their captions, at the end of the manuscript. Please remember to also send the graphics files separately. A separate file should be used for each graphic.

Sketches or schematic diagrams you supply should be as clear as possible. We can publish hand drawings if they are clear, but usually they will be redrawn. We can use illustrations that are already in electronic form, such as TIFF format. Or, we can redraw your figures, as long as their content is clear.

Photographs accompanying submissions can be black-and-white or color prints, color transparencies or slides. We can often use standard 3 by 5 inch prints, but enlargements are preferred because they can be scanned at higher resolution. Photos submitted with articles will be considered for use on the front cover of the Journal. Photos must be properly exposed and sharply focused. The print should possess a normal range of contrast. Prints having contrast that is too high or too low generally do not reproduce well and are hard to see.

If you take pictures, develop the prints and then scan them for submission. All photos should be scanned at 300 DPI minimum in grayscale or color to ensure maximum quality in printing. If you send electronic files they may be sent in color or in black and white/grayscale. (If you are not sure if the photo was scanned at 300 DPI, you can check to see if the image is approximately 1240-1400 pixels wide.) This will allow us to make up to a two-column (4 ½ inch wide) version for printing. Please keep in mind that you will need more pixels if your photo has a lot of detail. We prefer TIFF image files or JPG image files direct from the camera with minimal compression. Keep in mind that if you scanned a previously printed picture it may be necessary to turn on the "descreen" function in your scanning software to eliminate Moiré patterns in the finished scan.

Photo credit information should appear at the end of picture captions, in parentheses. For example: "Bob and Joe operate AO-40 while Sara observes, from the left: Bob Jones, KB3XYZ; Joe Hamop, K7ABC; and Sara Smith, VE3ZZZ." (WA4XXX photo.)

Concentrate on preparing a manuscript that is accurate, thorough and readable. To lure the reader into the presentation, use a descriptive and appealing title and a “deck”, or short blurb following the title. Look over recently published articles in *The AMSAT Journal* for examples. Indicate the scope of the article in its lead paragraph to encourage the reader to go further. Use relatively short sentences - ones that contain only the words necessary to convey the message. Break up the narrative occasionally with subheadings. (You can see subheadings in this document at the top of some of the paragraphs.)

After you think you have completed the article, set it aside for a day or so. Then read over the manuscript again and make any revisions that come to mind. Now is the time to correct errors such as incomplete and run-on sentences and any other mistakes that you may spot. You might even want to ask a ham friend to read the manuscript and comment on it to help you.

We prefer to receive your manuscript electronically instead of paper format to save the work of scanning or retyping the text. So if you have a computer with word processing software, please use it. We use IBM compatible PCs and Microsoft Word for most of our editing work. However, we can handle word processor files from just about any major DOS or Windows word processor in MS-DOS format on 3.5 or 5.25-inch floppy disks. If you're in doubt, send us your file in straight ASCII or in Microsoft Rich Text Format (RTF). Please use Times New Roman 10 point for the text.

Photographs

We can accept color prints or slides, black and white photographs in paper format or in electronic format. It is always best to send electronic picture files in the highest resolution possible. This will allow your photos to be printed with the highest resolution our printer uses. Often lower resolution files will look “pixelated” and will not show clearly in the publication. More follows:

- We accept digital images if the resolution is sufficient. Generally speaking, this means using at least a 1.2 megapixel (or greater) digital camera with the image resolution (sometimes referred to as “image quality”) set at maximum. For digital images, the resolution should be at least 300 dpi when the image is sized at 4 X 5 inches or larger. Consult your image-viewing software. It should have a “properties” function that will give you the specifications of any image.

- All photos, digital or otherwise, must include captions. Captions may be grouped in the text file at the end or in a separate text file with all the captions together. Tell us who or what is in your photos, where they were taken, what is happening and so on. If people are shown prominently in the photographs, you should supply their names and/or call signs if applicable. Don't write directly on the front or back of paper photos – your handwriting will show up in the scans of the photos. Write or type photo credit or descriptive information on a piece of paper and tape the paper to the back of the print or use adhesive-backed notepaper (Post-It Notes®).
- Please don't send images captured from Web sites or scanned from any other source without obtaining the written permission of the owner. Photos are typically copyrighted and you (and AMSAT) could be in violation of copyright laws!
- Please don't send pictures made on color laser or inkjet printers. The resolution and quality is typically not sufficient for use. We would rather have the photo file delivered electronically.

Illustrations

Sketches and/or schematic diagrams you supply should be as clear as possible so that our editor can work directly with them. If you can provide artwork drawn with CAD or other graphics programs that is ideal. If you supply schematics, provide them at the highest resolution possible, especially if there are small details.

All illustrations must include the following:

- Component labels and values (for example: C21 - .01 mF)
- Dimensions of all construction components (PVC tubes, wires, aluminum tubes, etc.)
- Text captions that clearly describe what is being shown in the graphics.
- Illustrations in AutoCad® are acceptable.

If you are an artist, we can also accept Adobe Illustrator, Photoshop, PowerPoint, Visio, Corel, Encapsulated Postscript (EPS) and other types of graphics files. If in doubt we will work with you to get the image into the proper format for placement in the Journal.

Spreadsheet Graphics

Keep in mind that the Journal is a black and white printed publication when you are formatting spreadsheet graphs and the like for publication. If multiple lines are on a graph in various colors they may be hard to read in black and white. Please add separate marks available in your spreadsheet program to identify individual graph lines. Also keep in mind the lighter line colors like yellow and

light blue may be invisible when your graph is printed in black and white. Use solid dark colors for the lines to ensure clarity and use the various point selections available in your spreadsheet software to identify the different lines. Please provide your spreadsheet file to us if possible. The Journal editors have access to Microsoft Excel and can open and work on the formatting of your graph if needed.

pride in having an article published in a quality, respected Journal that will be available to the Amateur Radio community for many years.

Deadlines

In general, Journal deadlines are as follows:

- January/February issue December 20
- March/April issue February 20
- May/June issue April 20
- July/August issue June 20
- September/October issue August 20
- November/December issue October 20

If you can get articles submitted sooner, then more time is available to edit and review. And it is more likely that your article will be published sooner. These deadlines may move some depending on a variety of issues. It's always better to submit early rather than late.

If your article is accepted ...

If your article is accepted, we will notify you. The editors will schedule your article for the next available issue. When your article is ready for publication, we will e-mail a copy to you (in Adobe PDF format) or mail it to you if you do not have e-mail. Obviously e-mail is more expedient and is the preferred method. This will be your "proof" copy. Check it carefully for errors and then contact us as soon as possible with any necessary changes. At that time we may ask you to sign a release allowing us to publish your work.

Compensation

AMSAT is a non-profit, volunteer organization. We do not provide compensation for articles submitted. We appreciate your efforts and contributions to the art of space communications, as do the members of our organization. Your contributions allow you to become known throughout the AMSAT community of highly skilled amateurs. You will also have the

Successful Hamfest Satellite Demos

By

Keith Pugh, W5IU

One of the best ways to promote Amateur Radio Satellites is to demonstrate how simple, inexpensive, and fun satellite operations can be in conjunction with an AMSAT Booth at a Hamfest or Convention. Demonstrations can also be very effective at Amateur Radio Club Meetings, Schools, and other groups. There are two key elements to successful demonstrations; planning and execution. Hopefully, this paper will identify these key elements and give you some ideas for your own use. These ideas are mostly common sense and have evolved over many years of doing demonstrations by myself and others throughout the country.

Planning the Demo –

I don't want to make this sound too rigorous because that may scare you off; however, some general guidelines are in order.

1. There are two universal truths to consider: ***Hams don't read and Hams are cheap.***
 - a. The first of these truths can be helped by having available some simple handouts outlining the "Birds" that are available along with basic information about each one, pass information for the next few days, and how to obtain additional pass information. Don't forget AMSAT Publications such as "Getting Started with Amateur Satellites" and the AMSAT Web Page. Brochures are available from Clint, K6LCS; Patrick, WA9EWK; and Gould, WA4SXM to use as guides to working the FM Birds.
 - b. Design your demonstrations to utilize simple, cheap, radios and antennas. Have several examples available if possible. HTs, separate transceivers, and converters. Antennas are a good place to show a variety: Arrow, Elk, Cheap LEO Antennas, and other "home brew." Personally, I use two Yaesu FT-817s a lot and sometimes supplement these radios with a Yaesu FT-530 and/or a Kenwood TH-D7A. I have also used a Yaesu VX-5R on several occasions.
 - c. Some useful sources of information are:

AMSAT Web Site: <http://www.amsat.org>

Cheap LEO Antennas:

<http://www.wa5vjv.com/references/Cheap%20Antennas-LEOs.pdf>

Cheap AZ-EL Antenna Positioner: http://www.amsat.org/amsat-new/echo/Az_El_Pos.pdf

AMSAT Field Operations files

Elk Antennas: <http://www.ElkAntennas.com>

Arrow Antennas: <http://arrowantennas.com/>

2. Know specifically which “Birds” will be coming over during Demo time and what mode(s) they are in.
 - a. Mode V/U FM – Most common and easiest to demo. Least equipment necessary. Full duplex equipment is desirable but not absolutely necessary.
 - b. Linear Transponders – SSB/CW – More difficult to demo but have the potential for longer QSOs and greater audience participation. Requires multi-mode, full duplex equipment.
 - c. Special modes such as V/S or U/S. Requires S Band down converter and S Band antenna in addition to basic equipment. Very good “bang for the buck” when effectively demonstrated. Only available when modes are available on the “Birds.” Given enough lead time, you may be able to influence the mode schedule on the “Birds” by requesting scheduling through the command stations or the satellite operation committee. This is most effective for large gatherings or other special events.
 - d. Don’t overlook value of “receive only” demonstrations using beacons, telemetry, etc. I like to use the CW Beacon on HO-68 as an illustration of Doppler.
3. Know your event and plan around its overall schedule.
 - a. Know the physical layout of the event site. It is important to know the geometry of the site vs. pass orientation. You may want to have several locations depending upon the passes to be used for demonstrations. It is necessary to get outside and you need to know the effects of local obstructions.
 - b. Know how to announce an upcoming demo. Be sure to announce where to gather for the demo. I usually tell folks to come to the AMSAT Booth and we’ll go from there unless there is some other easily identified meeting place. Not many Hamfests have a dedicated demo area like we have at Dayton.
 - c. Post planned demo passes on AMSAT-bb ahead of time to be sure folks are aware that you will be doing demonstrations so that there will be someone out there to talk to.
 - d. Post planned demo passes in the Hamfest schedule or on a poster in the AMSAT Booth.
4. Set up your equipment far enough in advance so that you have time to discuss it and the procedures to be used during the contact before contact time..
 - a. If you have the luxury of a dedicated demo area, the setup can be more elaborate. It is very helpful to have a portable power source

available. Antennas can be on an antenna positioner, rigs on a table, tracking computer available, computer controls shown as an alternate to manual, Sun shield for computers, equipment, and operators, etc. If using a laptop computer, devise a light shield to aid in viewing it in sunlight. Remember, once this setup is done, you must staff it as long as the equipment is in place which could be all day. This is what we do at Dayton. This is a very rewarding way to go and a lot of interest can be generated.

- b. Without a dedicated demo area, plan to haul equipment in and out of the building each time a pass comes over. You can set equipment up on a small table, antennas hand held or on an antenna positioner, and enlist Hams to help carry it all out to the site and back. This helps you and it makes them feel like a part of the demo. I do this at most Hamfests out of necessity. I also do it at Ham-Com in Texas to avoid as much of the Texas Summer Heat as possible.
- c. Especially if doing demos on linear transponders, recruit help from the crowd. It's a great opportunity to let one Ham operate the receiver, another operates the transmitter, and a third points the antennas. Of course this requires constant coaching on your part. In this type of operation, I usually operate the transmitter which involves talking and doing the in-pass Doppler correction.

**The "Three Musketeers"
doing a
Linear Satellite Demo in "Cowtown"**



**Doug
W5BL**

**Keith
W5IU**

**Douglas
KA2UPW/5**

Execution –

Execution sounds very *final* and it is where the “proof of the pudding” resides. Some of this has been touched on in the planning discussion but it will be re-emphasized here.

1. Be sure you have checked out your equipment, and yourself, before demo time. Do some practice before the demo to brush up on operating technique.
2. Refer to The Live OSCAR Satellite Status Page - <http://oscar.dcarr.org/> - to verify the operational status of your intended “Bird.” It is very embarrassing to plan a pass and find that the “Bird” is not-available for some reason. It’s quite helpful to have this available on the AMSAT Booth Computer if you have internet access.
3. Plan your demo as described above and then post your passes and times that you will be available on amsat-bb a couple of days in advance if possible. Don’t forget the callsign and the name of the Hamfest, Convention, or club/school group that the demo is being done for.
4. Announce the demo at the event on the PA system or by signs and posters. Have people meet at the AMSAT Booth or demo site. If it’s hot, cold, or wet outside, describe the operation while still inside at the AMSAT Booth or other indoor location.
5. Set up the equipment if not already done and verify local compass directions. You need to know for sure where North, South, East, and West are. This does not have to be known with great precision but you do need to know the general direction to expect the “Bird” to come from.
6. Start listening for the “Bird” at the appointed time. Move the antennas around the initial direction while listening for the “Bird.” For SSB/CW transponders it will be necessary to tune around for signals while also moving the antennas.
7. Establish contact(s) and move on to the next one. Keep it short on the “FM Birds” but do mention that you are doing a “Demo for ____.” On the “Linear Birds” feel free to rag chew for the whole pass if you are able to. The crowd will love it. Continue to make contacts as long as the pass lasts.
8. Conduct a “wrap-up” Q&A session immediately after the pass is over. Take as long as necessary to answer everyone’s questions. You can move back inside for this if the climate is not cooperating.
9. Follow up in the AMSAT Booth with discussion and distribution of books, software, etc. You will be surprised what a successful Demo will do for this activity.
10. Get ready for the next pass!

As you can see there is a lot involved but it is not overwhelming and will become easy and intuitive after a little practice and a few demos “under your belt.” The rewards are great – finding some new friends, introducing the Amateur Radio Satellites to some new and/or old Hams and other folks. **Last but not least – it’s fun!**

I’ll talk to you during my next Demo!

73 – Keith, W5IU

Work Satellites with your HT!

*Most hams already have the necessary equipment to work FM amateur satellites.
K6LCS' guide offers all the information you need to "work the birds."*

All cited resources are available to you on one, easy-to-navigate Web page:

<http://www.work-sat.com>

If you can program split frequencies in your HT (transmit on 2 meter and receive on 440), you can work the FM amateur satellites! In satellite AO-51's primary **VHF/UHF (V/U)** mode, the **UPLINK** frequency (**to** AO-51) for voice is 145.920MHz*. The **DOWNLINK** freq (**from** AO-51) is 435.300MHz*.

First, you need to know **WHEN** and **WHERE** the satellite will be passing over your location. There are several commercial computer programs that will tell you. In the home office, I use **Nova for Windows**^[1]. Outside, though, I use **PocketSat**^[1] on my Palm PDA or iPod touch/iPhone. On my MacBook Pro, **MacDoppler**^[1] is amazing. These programs are easily updated with satellite tracking data. But **free of charge** info is also available online at ...

heavens-above.com -or- amsat.org

Plug in your longitude and latitude coordinates on either or both of these free sites, and you can access all sorts of amateur satellite pass information.

The one "absolute" for success is to **open up your squelch**. We're talking "weak signals" from 500+ miles away - so don't expect the satellite to be strong enough to break squelch like your local repeater. Sure, it's a little noisy, but that's part of the process. Noise is also an aid in locating the satellite: When the frequency starts exhibit **QUIETING**, that's a sign that you are capturing the satellite's signal!

Improve your HT's stock antenna. For BNC connectors, **Pryme's** AL-800^[2] will make the difference. For SMA, the **Diamond** SRH-320a or **Smiley** 270A^[2] are good performers. Using an **Arrow** dual-band^[3] Yagi is better. If you prefer to homebrew your antenna, see the Notes^[4] for construction article citations.

Set up your radio to tune for the **Doppler effect** on the downlink. Start listening **above** the center frequency^[5] - you will **acquire** the satellite sooner and clearer. When the downlink gets scratchy or fuzzy, tune down 5KHz at a time, and reception should be clearer. With low power, only transmit when you can **clearly** hear the satellite. Follow the signal down in frequency as the pass continues.

Don't hold your whip antenna upright. Held in a vertical position, your transmitted signal is hitting land-based receivers. You need to tilt your HT's antenna so that it is ***perpendicular*** to the airborne satellite. Very few of the ham satellites are land-based (grin), so you must **TILT** your antenna about the same amount as the satellite's **ELEVATION**. You'll quickly get the hang of it and hear the difference!

Ideally, we should all be working the satellites in **full duplex** mode, where we can *simultaneously* listen to the downlink as we are transmitting. Although this method is preferred, it is not mandatory: Carefully monitor the downlink, and wait for a break in the conversations to announce yourself. You might find it helpful to record your sessions for later review. Even if you don't make a contact during a pass, a recording can help you recognize the callsigns, voices, and personalities of other operators. Pocket recorders are as inexpensive now as they have ever been. Some hams use headphones to monitor the downlink.

Knowing your grid square - and having a grid square map - is a quick way of identifying locations of what you will be hearing. The **ARRL** and **Icom** have grid square maps: Icom's is free and available at better ham radio stores^[6].

It just takes a little preparation and planning for working amateur satellites. Not every pass is workable with an HT — don't go after the sub-10° elevation passes. Choose passes wisely, working ones you know will give you better results.

When you clearly hear others, try to find a break in the action, and use the ITU-approved phonetics^[7] to announce your callsign, grid square, and op mode:

"KILO-SIX-LIMA-CHARLIE-SIERRA, D-M - ONE-THREE, handheld."

Check the AMSAT Web site for the AO-51 Control Team News – to make sure AO-51 is in a VHF/UHF mode to work with your HT.

Ask questions! Find an elmer or look up the **AMSAT**^[8] area coordinator for your area. Use the Work-Sat.com support YahooGroup for any questions!

**Clint Bradford, K6LCS – www.work-sat.com
clint@clintbradford.com**

Skype, Twitter: [clintbradford](#)

Updated 7/19/2010

Notes

Access this Web site for all citations, links, resources, and updates:

<http://www.work-sat.com>

[1] Nova for Windows is available from Northern Lights Software Associates' Web site at www.nlsa.com. PocketSat is available from Big Fat Tail's site at www.bigfattail.com. And MacDoppler is available at www.dogparksoftware.com.

[2] The Pryme AL-800 telescopes to 34" and collapses to 10". It is packaged with a 9" rat tail - which you can use for everyday use. Use caution with this massive, heavy antenna: It has the potential of placing a lot of stress on your radio's BNC connector.

[3] Arrow's Model 146/437-10WBP is a dual-band cross-Yagi design, with a diplexer built into the handle. It has three elements on 2M and 7 on 440. See it in action in the December, 2007 issue of CQ Magazine. Arrow's Web site: <http://www.arrowantennas.com>.

[4] Alex Diaz' Yagi-Uda plans, AMSAT's "Cheap and Easy" sat antenna articles, a tape measure beam construction article – and LOTS more – are all on the Antennas page at work-sat.com

[5] For example, here's how I have programmed my radios for **AO-51***:

Ch #	Name	TX Freq*	CTCSS*	RX Freq	CTCSS
101	51 +2	145.920*	67.0*	435.310	None
102	51 +1	145.920*	67.0*	435.305	None
103	51 MID	145.920*	67.0*	435.300	None
104	51 -1	145.920*	67.0*	435.295	None
105	51 -2	145.920*	67.0*	435.290	None

And here's how I have programmed my radios for **SO-50**:

Ch #	Name	TX Freq	CTCSS	RX Freq	CTCSS
201	50 +4	145.850	67.0	436.815	None
202	50 +3	145.850	67.0	436.810	None
203	50 +2	145.850	67.0	436.805	None
204	50 +1	145.850	67.0	436.800	None
205	50 74	145.850	74.4	436.795	None
206	50 MID	145.850	67.0	436.795	None
207	50 -1	145.850	67.0	436.790	None
208	50 -2	145.850	67.0	436.785	None
209	50 -3	145.850	67.0	436.780	None

[6] Icom's map is available as a .pdf file on Icom's Web site. Search their Knowledge Base for Article 5BUE54225A at <http://icomamerica.com> - or download at work-sat.com.

[7] Download the [ARRL's Handy Operating Guide](#) (FSD-220) at – you guessed it – work-sat.com.

[8] **AMSAT** *deserves your support!* Membership isn't that expensive, and members are entitled to discounts on AMSAT publications and satellite tracking software. Support the sats!

[*] Watch the [AO-51 Control Team](#) page for frequency changes and scheduled updates! What's your single source for links to the ops schedules for the popular FM birds? **work-sat.com** !



I've been a licensed amateur just since 1994, and involved with AMSAT the past five years. My "*Working Amateur Satellites with your HT*" presentation has proven to be popular, and has been given to several clubs and hamfests in Southern California ... as well as via EchoLink and Skype conferences. Some comments received ...

Clint has this magnetism - you never know what to expect. He started out with interesting trivia and gave prizes to the lucky winners. He is a very motivating speaker!

Your Web site took me from zero knowledge in 10/2009 to getting an HT and an Arrow. As of March 6, 2010, I have qualified for VUCC on the FM birds.
A great site for the beginner on the birds. You unmystify the birds.

I love the site and I greatly appreciate the information you have provided to get me going! Yours is a no-nonsense approach to working satellites and helpful documentation (tutorial). The photos really helped in understanding.

Simplicity ... the idea of working sats "sounds complicated" but that's really not the case. You keep the language simple, illustrations simple, and concept simple ... give folks the idea that any ham can do this (which they can) with the right equipment....if they follow the directions provided here.

Want a lively, hour-long ham satellite presentation at YOUR club? I have given my presentation several times via Skype: I prepare and send a customized .pdf slideshow ahead of time for you to project to your club, and we use Skype over the Internet for two-way audio.

Contact me via email – let's schedule a presentation!

Clint Bradford, K6LCS
Mira Loma CA US DM13
Email: clint@clintbradford.com